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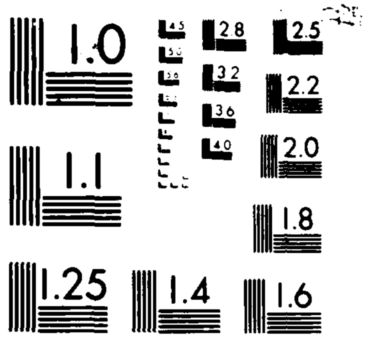

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THESIS

A GENERAL PURPOSE GRAPHICS SUPPORT
LIBRARY FOR THE ADA PROGRAMMING LANGUAGE
HOSTED ON THE ZENITH H/Z-100 COMPUTER

by

Thomas R. Brown, Jr.

December 1986

Thesis Advisor U.R. Kodres

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Listings of library routines developed are provided as well as a user's guide and demonstration programs. Potential areas for further investigation and development are suggested.
It is concluded that an Ada graphics library for microcomputers is feasible and practical.

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A General Purpose Graphics Support Library for the Ada Programming Language Hosted on the Zenith H Z-100 Computer

by

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B.S., Eastern New Mexico University, 1981

Submitted in partial fulfillment of the requirements for the degree of

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ABSTRACT

This thesis explores the requirements necessary to develop a graphics support library for the Ada programming language hosted on the Zenith H/Z-100 microcomputer. A prototype graphics library is implemented in 8086 assembly language embedded in an Ada package. The library operates with JANUS Ada under the CP/M-86 operating system.

Listings of library routines developed are provided as well as a user's guide and demonstration programs. Potential areas for further investigation and development are suggested.

It is concluded that an Ada graphics library for microcomputers is feasible and practical.

THESIS DISCLAIMER

The reader is cautioned that computer programs developed in this research may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure that the programs are free of computational and logic errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

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   Zenith
   H/Z-100

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I. INTRODUCTION

A. BACKGROUND

The Naval Postgraduate School (NPS) utilizes approximately fifty Zenith H Z-100 microcomputers in the microcomputer laboratories of the Computer Science Department. There were many reasons for choosing this particular computer, foremost of which is the hardware architecture [Ref. 1] and the availability of support software. The H Z-100's central processing unit (CPU) includes an INTEL 8085 8-bit processor and an INTEL 8088 16-bit processor. The simple architecture and instruction set of the 8085 processor supports the popular CP M operating system and is compatible with 8080 code. The more complex architecture of the 8088 processor is compatible with 8086 code and includes more internal registers (some usable as either 8 or 16-bit), extended addressing modes, and a more complex memory management scheme using segment registers. The 8088 processor supports the more advanced CP M-86 and MS-DOS operating systems.

An important feature of the H Z-100 is its display versatility. The basic H Z-100 includes an internal monochrome display and allows the addition of an additional external color monitor. The color monitor is of medium resolution with 640 horizontal and 225 vertical pixels (640 X 512 in the interlace mode). Three 64k pages of video RAM memory provide eight colors (or eight intensity levels with a monochrome monitor).

A primary function of the microcomputer laboratory is to support computer science courses providing special emphasis on tactical computer applications. According to Department of Defense policy [Ref. 2], "The Ada programming language shall become the single, common computer programming language for defense mission-critical applications. Effective 1 January 1984 for programs entering full-scale engineering development, Ada shall be the programming language." To assist in meeting this requirement, NPS provides courses which include the use of Ada in the development of tactical program applications programs. Most of these programs are run on the H Z-100 computers using the JANUS Ada compiler. To date, several validated Ada compilers have been approved for specific computer systems, with many more expected to be approved in the near future. However, as Patrice Wagner points

out [Ref. 3] there has been little measurable response within the computer graphics industry. An improvement in this area can be expected with the acceptance of the Ada Binding to the Graphical Kernel System (GKS) [Ref. 4] by the American National Standards Institute (ANSI) X3H3 committee on graphics standards. However, we cannot sit back and wait for industry to provide all the tools necessary to conduct Ada graphics education and research. Widespread use of Ada can be expected in the near future and with that use there will be increasing requirements for individuals with Ada graphics knowledge. The NPS has an obligation to assist the Navy in meeting those educational requirements.

B. PURPOSE

It is the intent of this thesis to develop an Ada language graphics programming capability by developing a low level design and partial implementation of an Ada graphics library which can be expanded to include a subset of the Ada language binding to the GKS. Functions to be included will be those primitives necessary for:

- clearing the screen
- setting a pixel
- drawing a line
- selecting a color
- filling polygons
- cursor control

These basic primitives will be implemented using 8086 assembly language embedded in an Ada package. The CP/M-86 operating system and the JANUS Ada compiler will be used for this implementation.

It is expected that the primary use for this software will be in courses which emphasize tactical applications of computers. It is becoming more and more common to find graphical displays in tactical systems. The ability of computers to provide graphical displays which aid in tactical decision making is widely recognized and the list of tactical applications utilizing graphical displays can be expected to grow as faster and better graphics displays are developed.

It is anticipated that this software will assist in gaining an insight into the feasibility of developing a GKS implementation for Ada on a microcomputer. As an immediate benefit, it will aid in the development of Ada graphics programs on the H/Z-100 computer.

C. THESIS ORGANIZATION

Chapter II begins with a brief overview of the architecture of the H Z-100 computer. The overview is presented to assist the reader in understanding the selection and implementation of the graphics algorithms. Next there is a brief discussion explaining the use of the JANUS Ada compiler and CP M-86 operating system. Included in this discussion is a description of parameter passing procedures in JANUS Ada. The remainder of Chapter II is devoted to providing a detailed description of the implemented graphics routines.

Chapter III provides a description of the test demonstration programs listed in Appendices B-E. Also included in this chapter is an evaluation of the H Z-100 color graphics capability. Shortcomings and system hardware performance are discussed.

Chapter IV includes recommendations for further research and program development using the H Z-100 computer.

Chapter V is the final chapter and includes the conclusion and general comments pertaining to the use of microcomputers and Ada in graphics programming.

Appendix A is a user's guide which describes the procedures available in the Ada graphics library. Also included are some programming tips on usage of the library procedures and sample procedure calls are provided as examples.

Appendices B-E are program listings of demonstration programs written in Ada. They are provided to demonstrate the use of the Ada graphics library as well as serving as a supplement to the user's guide.

Appendix F is a listing of the specification package for the Ada graphics library. The specification package defines the formats of all externally callable library procedures.

Appendix G is the assembly code listing of all procedures contained in the Ada graphics library.

II. ALGORITHMS

A. H/Z-100 ARCHITECTURE

The following overview of the H Z-100 architecture is presented in order to clarify the method of implementation of specific algorithms. Figure 2.1 is a block diagram of the basic architecture of the H Z-100 computer.

NPS's H Z-100 computers are in the process of being upgraded to include the Model ZVM-1330 color monitor, 192k of on-board cpu memory and three 64k pages of video RAM.

The display screen is formed by a matrix of 640 horizontal and 225 vertical pixels. Each pixel is mapped to a bit in each of the three color planes (red, green, and blue) in video RAM. Display management is provided by the video processor's CRT controller (CRT-C).

The CRT-C has two modes of operation: the character based mode and the pixel based mode. In the character based mode, the CRT-C is programmed for nine scan lines per character, 80 characters per line and 25 lines per screen. In the pixel based mode, the CRT-C is normally programmed to control a matrix of 640 X 225 pixels.

Mapping of video RAM to the screen is performed by the CRT-C to allow scrolling of the screen and management of displayable nondisplayable data. Mapping of the display to physical addresses in video RAM is organized such that 128 (numbered 0-127) consecutive bytes are allowed for each scan line. However, only 80 of the 128 bytes are used to control display of the 640 pixels per scan line. Bytes 80-127 of each line must not be used or erroneous data may be displayed. Additionally, the 225 displayable scan lines may be considered to be in sets of 16 lines of which only the first nine lines of each set are displayable.

When operating in the character based mode, the CRT-C is programmed to map around the non-displayable video RAM. However, in the pixel based mode, it is necessary to incorporate a mapping algorithm into graphics routines. This means that of the 400 scan lines, only 225 are displayable. In addition, the CRT-C is normally programmed so that the bottom character row (9 scan lines) is zeroed during vertical retrace time. This is done to keep uninitialized data from being displayed during scrolling. This means that only 24 of the 25 character rows or 216 of the 225

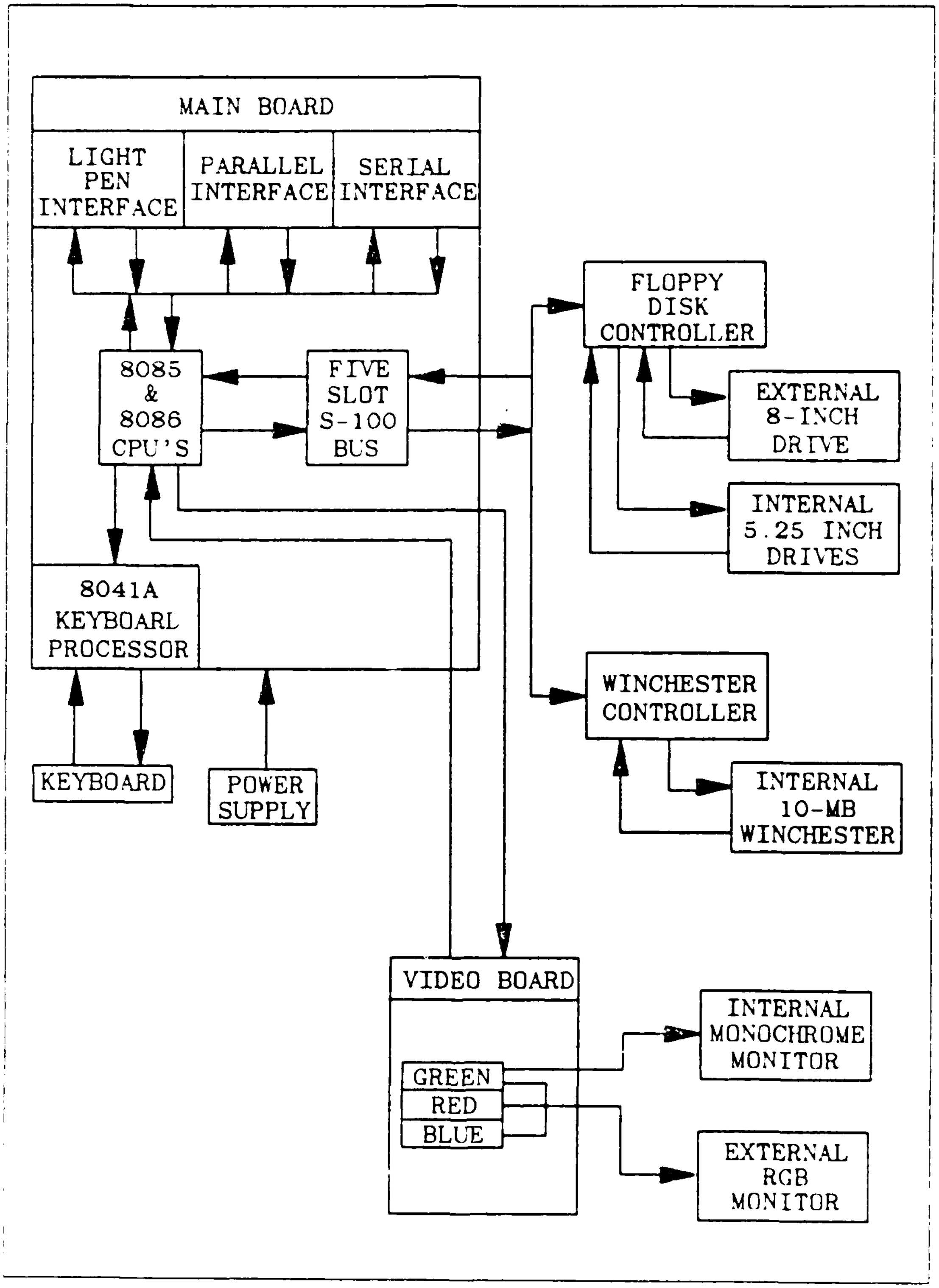

Figure 2.1 H/Z-100 Block Diagram.

displayable scan lines actually display data. The Ada graphics library has been designed to work within these restrictions in order to maintain compatibility with existing H Z-100 software. Figure 2.2 illustrates the display matrix including the scan line and pixel numbering system.

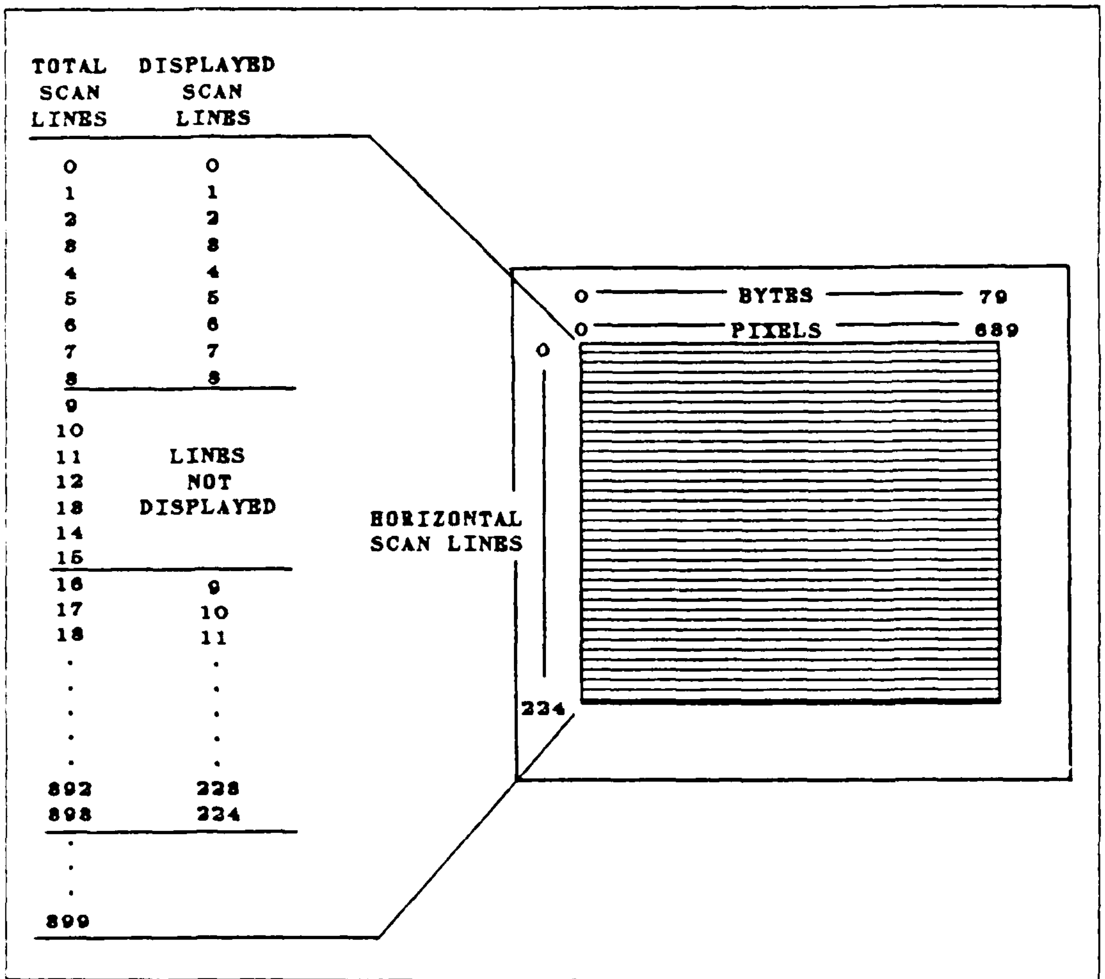

Figure 2.2 Display Matrix.

There are two ways in which to control writing into the individual color planes. The first method is by programming the video control register of the video logic board. With this method, when a write enabled color plane is accessed, all write enabled color planes are simultaneously written to. For example, if all three color planes are write enabled and the green color plane is written to, then the corresponding addresses in the

blue and red color planes will also be written to. However, this feature was found to be unsatisfactory when constructing a graphics picture consisting of multiple colors and adjacent or overlapping objects. Under these conditions, it was discovered that the only color plane which could be guaranteed to contain correct data was the one which was directly written to. Therefore, the algorithms implemented in the Ada graphics library utilize the second method which involves direct control over each of the three color planes. This means that the implemented algorithms must access all three color planes for each pixel that is set. [Ref. 1: pp. 4.30-4.38]

TABLE 1

COLOR PLANE ADDRESSES

COLOR PLANE	RAM ADDRESSES
blue	0C0000 - 0CFFFF
red	0D0000 - 0DFFFF
green	0E0000 - 0EFFFF

To produce color, the video RAM is divided into three main colors: red, green, and blue. Video RAM memory mapping of the three color planes is provided in Table 1 with all addresses in hexadecimal. The pixel seen on the color monitor is actually composed of three superimposed pixels, one in each color plane. By selecting combinations of the three basic colors, eight different colors may be displayed as indicated by Table 2 .

B. JANUS/ADA

An overview of the JANUS Ada compiler [Ref. 5] and the CP/M-86 operating system [Ref. 6] relating to the implementation of the Ada graphics library is presented to assist the reader in understanding the methods used to implement the graphics algorithms. The graphics routines are available to an Ada language program by linking to library routine ADAGRAPH.LIB (Appendix F).

ADAGRAPH.LIB is implemented as an Ada specification package. That package contains the specifications of the callable library procedures plus a list of the variables used by the Ada graphics library assembly code. The assembly code is

included in Ada assembly package ADAGRAPH.ASM (Appendix G). The following steps are used to compile, assemble, and link the Ada graphics library.

(1) JANUS ADAGRAPH.LIB

(2) JASM86 ADAGRAPH

(3) JLINK ADAGRAPH

TABLE 2

COLOR TABLE

GREEN	RED	BLUE	DISPLAY COLOR
0	0	0	black
0	0	1	blue
0	1	0	red
0	1	1	magenta
1	0	0	green
1	0	1	cyan
1	1	0	yellow
1	1	1	white

Parameters are passed in Ada by pushing them onto the system stack. Discrete and access data type parameters of mode **IN** are passed by value. All other data type parameters and modes are passed by reference. Upon entry to a procedure, the top of the stack contains the return address. Parameters or parameter addresses appear on the stack with the last parameter nearest the top of the stack. Figure 2.3 is an example illustrating the format of a procedure specification and the corresponding location of parameters on the system stack when the procedure is executed.

If the parameters passed are only of mode **IN**, then the assembly procedure must remove those parameters from the stack and leave only the return address on top of the stack before executing a **RET** instruction to return from the procedure to the calling program. If the parameter list includes any mode **OUT** or **IN OUT** parameters, then the stack must be in the same configuration upon exit from the procedure as it was upon entry.

When it is desired to access parameters on the stack without altering the stack contents, then the BP register should be used. The following steps illustrate how this can be performed.

```
(1)  MOV  BP, SP     ;Copy SP register to BP register
```

```
procedure INQUIRE_COLOR( x_pos,  y_pos: in INTEGER;
                         color:  out INTEGER);

                   |                  |
        SP  --->   --------------------  <--- Top of Stack
                   | Return Address   |
        SP+2 --->  --------------------
                   | color; address   |
        SP+4 --->  --------------------
                   | y_pos; value     |
                   --------------------
                   | x_pos; value     |
                   --------------------
                   |                  |
```

Figure 2.3 Parameter Passing.

```
(2)   MOV   AX, [BP+2]  ;Move last variable to AX register
(3)   MOV   BX, [BP+1]  ;Move next to last variable to BX
```

C. GRAPHICS ALGORITHMS

The following paragraphs provide a detailed explanation of each graphics routine in the Ada graphics library and the algorithms used to implement those routines. Several of the low level subroutines used to implement the library are not available to the user and are therefore not listed in the User's Guide (Appendix A). Only those graphics routines that have an apparent use in an Ada language program were made externally callable.

1. Clear Screen (CLS)

The CLS routine will clear the screen in one frame time (approximately 16.7 ms for 60 Hz operation). The CLS algorithm [Ref. 1: p. 4-46] is described in the following steps:

(1) Input and save the video status from I/O port D8(hex).

(2) Blank the screen by outputting 0F(hex) via I/O port D8(hex).

(3) Output a "0" in bit 3 of the B control port DB(hex). This signals the video controller that the bit planes will be set to zero. This step is performed by executing an input, modify, and output sequence.

(4) Output a "0" to bit 3 of the A control port D9(hex). This enables the video processor's CLRSCRN signal.

(5) Wait for one frame period to allow time to reset all of video RAM.

(6) Output a "1" to bit 3 of port D9(hex). This disables the CLRSCRN signal.

(7) Restore video status that was saved in step 1 by outputting the saved status via port D8(hex).

2. **Color Selection**

When the color routine is called, it is passed an integer identifying the selected color. In normal operation, once a color has been selected, it remains the system color until changed by another call to the color procedure.

The color procedure uses the color code parameter to perform two basic functions. First, it sets each of the three color plane variables to base addresses which will be used by other procedures to initialize the E segment register for addressing the the required color planes. Second, a control word (78 hex) is output to the video control register via I/O port D8(hex). The control word disables the simultaneous write capability of the video controller. Table 3 lists the data used to control color selection.

TABLE 3

COLOR CONTROL

Color Code	Color	Var. 1	Var. 2	Var. 3
0	white	C000	D000	E000
1	cyan	C000	E000	E000
2	magenta	C000	D000	D000
3	blue	C000	C000	C000
4	yellow	D000	E000	E000
5	green	E000	E000	E000
6	red	D000	D000	D000
7	black	----	----	----

In normal operation, control word bits 0, 1, 2, 7 are set to "0" bit 3 is set to "1" and bits 4-6 are used to control the simultaneous write capability of video RAM. The color routine does not affect the contents of the E segment register, but simply initializes variables which will be used to modify the E segment register as required. This is done to maintain compatibility with other H/Z-100 software which uses the E segment register, e.g., the standard I/O library.

3. **Video Ram Addressing**

Mapping of the video to the screen is accomplished in two steps. The first is performed by the ADJ_SL procedure which accepts a Y position in the range 0-215

and maps that position to a displayable scan line. This mapping is described by the equation Scan_Line_Number = Y+(Y Mod 16)*7. This function is implemented by a simple counter which adds seven to the scan line count for each block of 16 lines. Step two is performed by the REL_VID_ADDR procedure. This procedure uses the X position and scan line number to calculate the corresponding relative byte address in video RAM. This is a relative address since it is independent of the color plane. Relative byte addresses are calculated using the formula:

```
Relative_Address = Y * 128 + X Mod 8.
```

Prior to address calculation, error checking is performed to insure that:

```
0<=X<=639 and 0<=Scan_Line_Number<=376.
```

4. **Pixel Display**

Displaying of individual pixels is performed by procedure SET_PIXEL. Procedure SET_PIXEL accepts an (X,Y) coordinate and performs the following steps:

(1) Calls procedure ADJ_SL to map the y coordinate to a displayable scan line.

(2) Calls procedure REL_VID_ADDR to get the relative byte address.

(3) Calculates the relative bit position within a byte based on the x coordinate.

(4) Initializes segment E to provide the base address for the desired color plane.

(5) Sets the selected pixel by writing to the relative address.

(6) Repeats steps 4 and 5 for each of the three color plane variables.

5. **Line Drawing**

Line drawing may be performed by either procedure DRAW_LINE or procedure DRAW_MLINE. The two procedures use the same algorithm for line drawing with the difference being in the way that intersecting lines are displayed. Procedure DRAW_LINE always displays the most recently drawn line on top while procedure DRAW_MLINE mixes the colors of crossing lines at the point of intersection. The line drawing algorithm is an adaptation of a general integer digital differential analyzer (integer DDA) algorithm described by Marc Berger [Ref. 7: pp. 41-45]. The general integer DDA has been expanded from four to six cases and a smoothing function has been included. The two additional cases were added to handle the special cases where a line is either vertical or horizontal. The smoothing function was added to improve symmetry in the staircase effect which is inherent with raster scan displays.

The integer DDA algorithm is an iterative process which operates by taking unit steps along the X and or Y axis beginning at line start and continuing to line end.

The direction of each step is determined by an error variable which identifies whether the present position is above or below the ideal line. After each step, the error variable is updated based on the direction of movement. The initial value of the error variable is determined by the smoothing function which biases the error variable so that the first pixel step in one axis is delayed based on the slope of the line. Without this bias the DDA algorithm frequently makes an erroneous first move. An example of an extreme case illustrates this point. For example, if a near horizontal line with a single pixel change in Y is drawn by the unbiased algorithm the pixel step will occur at line start. However, in the biased algorithm the pixel step will occur at the approximate midpoint of the line. This provides an obvious enhancement in symmetry to a staircase line.

Implementation of the six cases in the line drawing algorithm assumes that the input coordinates are ordered so that Y_START <= Y_END. This ordering is enforced by the line drawing procedure prior to plotting a line.

In the description of the six cases which follows, initial values of X and Y are respectively X_START and Y_START and the following definitions apply.

- X — X coordinate
- Y — Y coordinate
- X_START — X coordinate of line start
- Y_START — Y coordinate of line start
- X_END — X coordinate of line end
- Y_END — Y coordinate of line end
- DX — X_END - X_START
- DY — Y_END - Y_START
- E — error

(1) DY = 0.

This is a horizontal line.

```
initialize
  X:=X_START
  Y:=Y_START
end initialize
repeat until (X=X_END)
  X:=X+1
  plot(X,Y)
```

```
        end repeat
    (2)  DY <= DX, DX > 0, and DY > 0.
This is a line with positive slope between 0 and 1.
        initialize
          X:=X_START
          Y:=Y_START
          E:=DX/(DY+1)
        end initialize
        repeat until (X=X_END & Y=Y_END)
          if (E<0) then
            X:=X+1
            E:=E+DY
          otherwise
            X:=X+1
            Y:=Y+1
            E:=E-DX+DY
          end if
        end repeat
    (3)  DX < DY, DX > 0, and DY > 0.
This is a line with positive slope greater than 1.
        initialize
          X:=X_START
          Y:=Y_START
          E:=DY/(DX+1)
        end initialize
        repeat until (X=X_END & Y=Y_END)
          if (E<0) then
            X:=X+1
            Y:=Y+1
            E:=E-DX+DY
          otherwise
            Y:=Y+1
            E:=E-DX
          end if
        end repeat
```

(4) DX = 0.

This is a vertical line.

```
initialize
  X:=X_START
  Y:=Y_START
end initialize
repeat until (Y=Y_END)
  Y:=Y+1
end repeat
```

(5) DY >= ABS(DX), DX < 0, and DY < 0.

This is a line with negative slope between -1 and 0.

```
initialize
  X:=X_START
  Y:=Y_START
  E:=DX/(DY+1)
end initialize
repeat until (X=X_END & Y=Y_END)
  if (E<0) then
    X:=X-1
    E:=E+DY
  otherwise
    X:=X-1
    Y:=Y+1
    E:=E+DX+DY
  end if
end repeat
```

(6) ABS(DX) < DY, DX < 0, and DY < 0.

This is a line with negative slope less than -1.

```
initialize
  X:=X_START
  Y:=Y_START
  E:=DY/(DX+1)
end initialize
repeat until (X=X_END & Y=Y_END)
  if (E<0) then
```

```
      X:=X-1
      Y:=Y+1
      E:=E+DX+DY
    otherwise
      Y:=Y+1
      E:=E+DX
    end if
  end repeat
```

6. **Circle Drawing**

Circle drawing is performed by passing the (X,Y) coordinate of the circle center and a radius to procedure CIRCLE. The algorithm executed by the circle drawing routine is an implementation of Bresenham's circle algorithm described by Hearn and Baker [Ref. 8: pp. 67-69]. In this implementation, the algorithm has been modified to include a correction factor to compensate for the X:Y pixel ratio of the raster display.

Bresenham's algorithm takes advantage of the symmetry of a circle in providing an efficient incremental method for plotting a circle. In this algorithm, eight points are plotted for each parameter calculation. Although multiplications are required in parameter calculations, the multiplier is a power of 2, so all multiplications can be reduced to a less costly shift operation. Figure 2.4 is a flow chart representation of the implemented version of Bresenham's algorithm.

7. **Color Testing**

The color of an individual pixel may be determined by passing an (X,Y) coordinate to procedure INQUIRE_COLOR. This procedure will determine the pixel color and return an integer value defining the color code. Color codes are listed in Table 2 .

The color testing algorithm uses the (X,Y) coordinate to calculate a relative byte address. It then uses the X coordinate to generate a bit mask to identify the specific bit location within a byte. The relative byte address and bit mask are then used to test the corresponding address in each of the three color planes. This test identifies the color components contained in that pixel and a color code is returned to the calling program.

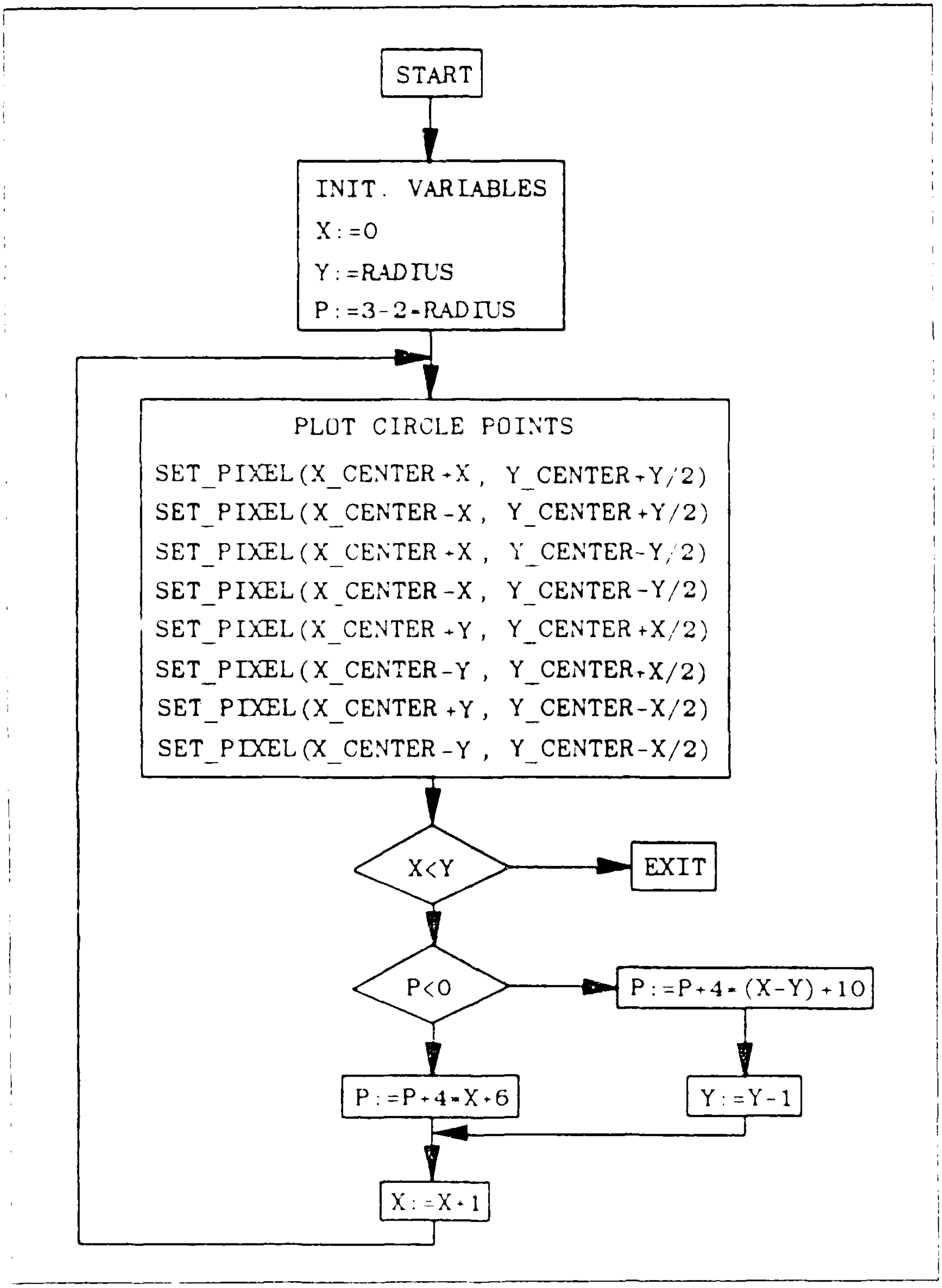

Figure 2.4 Bresenham's Circle Algorithm.

8. Area/Polygon Filling

Filling may be accomplished by calling either the procedure BOUNDARY_FILL or procedure AREA_FILL. Both of these procedures use algorithms based on a 4-connected boundary-fill algorithm described by Hearn and Baker [Ref. 8: pp. 92-93]. The 4-connected boundary-fill algorithm accepts as input the (X,Y) coordinate of an interior point of an area bounded [illegible] color and a fill color. Starting at the initial (X,Y) [illegible] neighboring points ((X+1,Y), (X-1,Y), (X,Y+1), (X,Y-1)) [illegible] a different color than the boundary, then it is set to the fill [illegible] new point are tested. This procedure continues until all [illegible] area have been tested. Figure 2.5 is a recursive Pascal 4-connected [illegible] procedure from Hearn and Baker [Ref. 8: p. 93], which forms the [illegible] following procedures.

```
procedure boundary_fill(x, y, fill_color,
                        boundary_color: integer);
 var present_color: integer;
  begin
   present_color := inquire_color(x, y);
    if (present_color <> boundary_color) and
     (present_color <> fill_color) then
     begin
      set_pixel(x, y, fill_color);
      boundary_fill(x+1, y, fill_color, boundary_color);
      boundary_fill(x-1, y, fill_color, boundary_color);
      boundary_fill(x, y+1, fill_color, boundary_color);
      boundary_fill(x, y-1, fill_color, boundary_color);
    end
  end;
```

Figure 2.5 Pascal Boundary-Fill Procedure.

Procedure BOUNDARY_FILL is a recursive routine whose input parameters include a beginning (X,Y) coordinate, a fill color, and a boundary color. This routine uses the 4-connected fill algorithm to fill an area bounded by the specified boundary color.

Procedure AREA_FILL is a recursive routine whose input parameters include only a beginning (X,Y) coordinate and a fill color. This routine uses the 4-connected fill algorithm to fill a contiguous area of the same color as that at the beginning (X,Y) coordinate.

The actual implementation of each of the two fill procedures is subdivided into two procedures. The first procedure initializes constant variables and then calls the second procedure. The second procedure is used for successive recursive calls. This technique minimizes the number of parameters which must be passed on each successive recursive call.

An individual call to either of the fill procedures can fill an area of at most a few square inches. Attempting to fill a larger area may result in a stack overflow error. This is an implementation limitation which can be circumvented by subdividing a large area into smaller areas, each of which may be filled separately. An exact upper limit on the size of an area which may be filled by a single call to a fill procedure is difficult to predict since it depends on the starting point within a specified area. Additionally, area filling is an inherently slow process due to the large number of calculations involved.

9. **Cursor Control**

The "+" symbol is used to represent a graphics cursor. Cursor positioning is controlled by procedures SET_CURS and RESET_CURS. Procedure SET_CURS accepts an (X,Y) coordinate and displays a cursor centered at that coordinate. Procedure RESET_CURS accepts an (X,Y) coordinate as input and erases a block of addresses surrounding that coordinate. Both procedures affect only the color planes that are enabled by the current system color.

Management of the cursor display and positioning is a responsibility of the user program. A cursor is not automatically displayed nor is there a limit on the number of cursor symbols which may be displayed concurrently.

The cursor symbol is composed of nine pixels with the center of the cursor being the reference point for positioning. In order to be able to position the cursor at any (X,Y) screen coordinate, it is necessary to consider individual components of the cursor. The vertical dimension (5 pixels) of the cursor spans five different relative byte addresses in video RAM. Additionally, the horizontal dimension (5 pixels) of the cursor may require an additional byte of memory. Whether an additional byte is required depends on the relative position within a byte of the cursor center. If the cursor center is near either end of a byte, then either the next lower or next higher byte from cursor center will also be required to display the cursor.

The set cursor algorithm uses the (X,Y) coordinate to calculate five relative byte addresses. These addresses represent a block on the screen which will contain the

cursor. The algorithm then uses the X coordinate to determine which of the eight bit positions within a byte represents cursor center. Then one of eight possible bit patterns is generated to represent the cursor. Resetting a cursor requires less program steps since a block of seven relative byte addresses are erased without regards to the exact position of the cursor within the block.

III. PERFORMANCE AND EVALUATION

A. DEMONSTRATION PROGRAMS

Four demonstration programs are provided in Appendices B-E. Those programs along with the user's guide in Appendix A, will aid the user in writing graphics programs using the Ada language.

1. Program AGTEST1

Program AGTEST1 draws a test pattern demonstrating the use of color selection, line drawing, circle drawing, and filling. This test uses ADAGRAPH procedures COLOR, SET_CURS, CIRCLE, DRAW_LINE, BOUNDARY_FILL, and AREA_FILL.

2. Program AGTEST2

Program AGTEST2 draws a pattern consisting of two sets of curves and a color wheel illustrating the eight available colors. AGTEST2 uses ADAGRAPH procedures COLOR, DRAW_LINE, DRAW_MLINE, CIRCLE, and AREA_FILL.

3. Program AGTEST3

Program AGTEST3 demonstrates interactive control of the graphics cursor. The user is asked repetitively to enter an (X,Y) coordinate. The program then displays a cursor centered at that coordinate and erases the previous cursor.

4. Program AGTEST4

Program AGTEST4 begins by drawing a circle of the approximate maximum area (approximately seven square inches) that can be filled by a single call to one of the fill procedures. It then fills the circle and goes on to demonstrate how polygons may be drawn by setting resetting individual pixels. It also demonstrates filling an area containing an object. AGTEST4 uses ADAGRAPH procedures COLOR, SET_PIXEL, RESET_PIXEL, CIRCLE, BOUNDARY_FILL, and AREA_FILL.

B. ADA GRAPHICS LIBRARY LIMITATIONS

The Ada graphics library presented in this thesis was developed as a prototype. Limitations of the library procedures should not cause significant problems to the user as long as the guidelines presented in the user's guide (Appendix A) are followed. The only known procedures which can cause a catastrophic failure if limits are exceeded are the fill procedures. The fill procedures can fill at most a contiguous area of

approximately seven square inches. Even filling a seven square inch area may cause an error if the starting point is not near the center of the area. However, if the user will limit the size of contiguous areas to be filled to approximately 3-4 square inches, then the probability of failures is very low. The reason for this limitation is that the fill routines are implemented as recursive procedures. As a recursive procedure, each level of recursion requires that three more parameters be pushed onto the system stack. Attempting to fill too large an area simply results in a stack overflow.

Another area of inconvenience for the user may occur in attempting to use the graphics library along with other libraries, e.g., the standard I O library. The standard I O library procedure **GET** automatically causes scrolling of the display screen by one character row each time it is executed. This is an obvious problem when used in concurrence with a fixed position graphics display.

C. H/Z-100 HARDWARE LIMITATIONS

A potential problem area for the user is due to the limited number of colors (8) available for display. This may be particularly inconvenient when writing interactive programs using the graphics cursor or any other symbols which are to be moved within the display. Management of movable objects can become very costly in terms of both processing time and amount of program code. The H Z-100, while comparable to many other microcomputers, is still quite slow in displaying a complex graphics picture. One method of optimizing the management of moving objects in the display is to restrict those objects to a dedicated color plane. If this is done, then updating the position of a moved object can be done without disturbing the graphics objects defined in the other color planes. A disadvantage of this approach is that there are only three color planes available to begin with and by dedicating one color plane to something like a cursor reduces the colors available for other objects from eight to four.

D. TIMING MEASUREMENTS

Table 4 provides a summary of timing measurements performed to determine average graphics processing times for the most critical operations. Times represented in the table are average times that one would expect to encounter in a call to Ada graphics library procedures when drawing a graphics picture.

The fill procedures are quite slow due to the large number of steps involved in testing and setting each pixel and the additional overhead related to a recursive procedure. The timing differences between drawing horizontal vertical lines and

TABLE 4

PERFORMANCE RESULTS

Operation	Time per Pixel (ms)
Fill	3
Draw Line	
Horiz./Vert.	.54
Diagonal	.64
Set/Reset Pixel	.58

diagonal lines is due to the two additional cases which were implemented in the line drawing algorithm. Those cases were added to handle the special cases where a line is either vertical or horizontal. In those cases, since the slope of the line is not used in plotting the line, less calculations are required than when plotting a diagonal line.

Setting resetting of individual pixels by all of the graphics procedures is slowed by the overhead in address calculation of the bit mapped display. This is primarily a weakness in the design of the video processor of the H/Z-100. However, it would be interesting to see if a significant speedup could be realized if a lookup table was used to aid in pixel addressing instead of a pure mathematical addressing algorithm.

IV. RECOMMENDATIONS FOR FUTURE DEVELOPMENT

Any future additions/modifications to the Ada graphics library should consider the following:

(1) The feasibility of implementing a nonrecursive fill routine.

(2) Development and implementation of different I/O procedures that are more compatible with a graphics display to replace those in the standard I/O library. In particular, these procedures should allow placement of alphanumeric symbols at any screen coordinate, not just the predefined character positions. Any scrolling of the screen should also be strictly under the control of the user program.

(3) The possibility of optimizing some of the existing procedures. For example, perhaps the mapping from a Y coordinate to a displayable scan line could be performed more efficiently by a lookup table. But, would the time savings justify the additional memory required?

(4) The feasibility of developing and implementing a subset of the GKS standard as a level of abstraction above the primitives provided in the Ada graphics library.

(5) The feasibility of networking two or more H/Z-100 computers to provide interactive operator communication on one system while providing a graphics display on another.

(6) The feasibility of modifying the structure of the Ada graphics library so that it is compatible with the MS-DOS operating system hosted on the H/Z-100.

V. CONCLUSION

The implementation of the Ada graphics library on the H Z-100 computer has proven the feasibility of developing Ada graphics programs on a microcomputer. The H Z-100 is certainly suitable for educational purposes but its ability to meet real time tactical requirements is limited. This limitation is not unique to the H Z-100, but is a general limitation of most microcomputers available today. We can expect this limitation to ease significantly over the next several years as low cost multiprocessor systems are developed.

The Ada graphics library was implemented as low level primitives necessary to interface with and control the H Z-100 hardware. The library functions were not designed in accordance with any recognized standards. However, the functions were designed with graphics standards in mind. The implementation of a higher level GKS standard graphics library would be able to use most of the present Ada graphics library primitives to interface with the H Z-100 hardware. The implementation of a GKS standard as a level above the machine dependent Ada graphics library would assist in making any developed Ada language graphics programs transportable to other computers. The benefits which may be realized from a standard interface to a language are obvious with the high costs of developing software. Although the architectural limitations of the H Z-100 are not compatible with a full implementation of the GKS standard, the educational benefits that could be realized from even an implementation of a subset of the GKS standard warrants furtther investigation.

The limited capabilities of the H Z-100 may limit its suitability for many operational tactical applications, however, it can be a useful system for program development. With the support of the Ada graphics library, the H Z-100 can assist in performing further research into such tactical programming applications as the Navy Tactical Data System (NTDS). The ability to perform research in this area could be further enhanced by the development of a GKS standard graphics library for the H Z-100 computer.

APPENDIX A

USER'S GUIDE

1. INTRODUCTION

Twelve graphics procedures are available to the user. These procedures are included in **ADAGRAPH.LIB** which is callable from the Ada programming language. Appendices B-E provide four example programs demonstrating the linkage and calling procedures necessary to use the Ada graphics library. Procedures available to the user are:

```
 (1)  CLS
 (2)  COLOR(color_code: in INTEGER)
 (3)  INQUIRE_COLOR(x_coord, y_coord: in INTEGER;
                    color_code: out INTEGER)
 (4)  SET_PIXEL(x_coord, y_coord: in INTEGER)
 (5)  RESET_PIXEL(x_coord, y_coord: in INTEGER)
 (6)  DRAW_LINE(x_start, y_start, x_end, y_end:
                in INTEGER)
 (7)  DRAW_MLINE(x_start, y_start, x_end, y_end:
                in INTEGER)
 (8)  CIRCLE(x_center, y_center, radius: in INTEGER)
 (9)  BOUNDARY_FILL(x_coord, y_coord, fill_color,
                    boundary_color: in INTEGER)
(10)  AREA_FILL(x_coord, y_coord, fill_color: in INTEGER)
(11)  SET_CURS(x_coord, y_coord: in INTEGER)
(12)  RESET_CURS(x_coord, y_coord: in INTEGER)
```

Following the description of each function is an example of the Ada language call to the described procedures. It should be noted that for all procedures that require an (X,Y) coordinate that the allowable range of X is 0-639 and the allowable range of Y is 0-216.

2. CLEARING THE SCREEN

Most graphics programs will require clearing the display screen before displaying graphics data. This is best performed by calling procedure CLS. This procedure takes

advantage of a built-in hardware feature which allows resetting all of video RAM in one frame period (approximately 16.7 ms).

```
-- Clear the screen
CLS;
```

3. COLOR SELECTION

The H Z-100 has the capability of displaying up to eight different colors. Color selection is performed by calling procedure COLOR and passing a color code parameter identifying the desired color. Table 5 lists the colors available and their respective color codes. Black is not listed as a color option since it is the only color which is displayed by resetting a pixel, i.e., writing a "0" to that pixels corresponding addresses in video RAM. All other colors are displayed by writing a "1" in the appropriate relative address of the color planes required to produce the desired color. If a pixel is to be reset to black then the RESET_PIXEL procedure should be used.

```
--Set system color to green
COLOR(5);
```

TABLE 5

COLOR CODES

COLOR CODE	COLOR
0	white
1	cyan
2	magenta
3	blue
4	yellow
5	green
6	red

4. COLOR TESTING

To determine the color to which any particular pixel has been set, use procedure INQUIRE_COLOR. Input parameters to this procedure are the (X,Y) coordinate of the selected pixel. The procedure returns the color code (Table 5) of the pixel located at that coordinate.

```
--Get color of pixel at (X,Y) coordinate (50,60)
```

INQUIRE_COLOR(59, 60, color);

5. PIXEL SETTING/RESETTING

Procedures SET_PIXEL and RESET_PIXEL are provided for controlling individual pixels. Procedure SET_PIXEL accepts an (X,Y) coordinate as input parameters and sets the corresponding pixel to the current system color. Procedure RESET_PIXEL accepts an (X,Y) coordinate as input parameters and resets the corresponding pixel to black.

```
--Set pixel at location (70,50) to current system color
SET_PIXEL(70, 50);
--Reset pixel at location (50,50) to black
RESET_PIXEL(50, 50);
```

6. LINE DRAWING

Procedures DRAW_LINE and DRAW_MLINE are provided for drawing lines. Both procedures accept as input parameters the (X,Y) coordinates of the end points of a line. A line of the current system color is then drawn connecting those end points. If procedure DRAW_LINE is used, then intersecting lines will be displayed with the last line drawn on top. If procedure DRAW_MLINE is used for drawing lines then the color at the point of intersection of intersecting lines is the combined color of the individual lines.

```
--Draw a line from coordinate (100,50) to
--coordinate (200,75). This line will be
--drawn on top of any line it intersects.
DRAW_LINE(100, 50, 200, 75);
--Draw a line from coordinate (100,25) to
--coordinate (10,15). This line will mix
--colors at the point of intersection with
--any lines that it intersects.
DRAW_MLINE(100, 25, 10, 15);
```

7. CIRCLE DRAWING

Procedure circle will draw a circle of the present system color. Input parameters to this procedure include an (X,Y) coordinate identifying the circle's center position and a radius length measured in units based on the number of pixels (640) in the X axis

of the video display. The circle drawing algorithm draws a circle with automatic corrections made based on the x:y linear pixel ratio (2:1) of the color monitor, i.e., the circle radius is twice as many pixels in the X axis as it is in the Y axis.

--Draw a circle of radius 50 units and

--centered at coordinate (300, 100).

CIRCLE(300, 100, 50);

8. AREA/POLYGON FILLING

Procedures BOUNDARY_FILL and AREA_FILL are available to perform filling operations. The user is cautioned that the filling algorithm has an upper limit on the size of an area (approximately seven square inches) which may be filled by a single call to either of the fill procedures. Larger areas may be filled by partitioning the larger area and filling the individual partitions. The user can generally avoid problems by limiting all fills to a contiguous area of not more than 3-4 square inches.

Procedure BOUNDARY_FILL accepts as input parameters an (X,Y) coordinate identifying the starting point, a fill color code, and a boundary color code (Table 5). The procedure begins filling from the starting (X,Y) coordinate and sets all pixels within the defined boundary to the designated fill color. The boundary must be a single color defined by the boundary color code.

Procedure AREA_FILL accepts as input parameters an (X,Y) coordinate identifying the starting point and a fill color code (Table 5). The procedure starts at the input (X,Y) coordinate and sets all pixels in a contiguous area which are the same color as the pixel at the (X,Y) starting coordinate to the specified fill color. This procedure can fill an area which is bounded by different colors since filling is based on the color of the area to be filled.

--Beginning at coordinate (50,75), fill an area

--with blue that has a red boundary.

BOUNDARY_FILL(50, 75, 3, 6);

--Fill a contiguous area with green. An internal

--point in that area is coordinate (100,100).

AREA_FILL(100, 100, 5);

I. CURSOR CONTROL

Procedures SET_CURS and RESET_CURS are provided for cursor control. The graphics cursor controlled by these procedures is a "+". The center of the cursor is

used as a reference point for cursor placement. All management of cursor display is the responsibility of the user. The cursor is simply a special graphics symbol which the user may display and erase. The number of cursor symbols which may be displayed at any point in time is determined solely by the user's program.

Procedure SET_CURS accepts as input an (X,Y) coordinate and displays a cursor symbol of the present color at that coordinate. Procedure RESET_CURS accepts as input an (X,Y) coordinate and resets a block of relative memory addresses centered at the corresponding (X,Y) coordinate. The color planes affected are determined by the present system color. It is suggested that if the user desires to use the cursor as a background symbol then the cursor color should be restricted to a single color plane (red, green, or blue) that is dedicated to cursor display. If this is not done then a management scheme must be implemented in the user program to maintain the integrity of non-cursor graphics data when setting resetting the cursor.

```
--Display a green cursor at coordinate (150,100).
COLOR(5);
SET_CURS(150, 100);
--Erase a green cursor at coordinate (50,75).
COLOR(5);
RESET_CURS(50, 75);
```

APPENDIX B

GRAPHICS TEST 1

```
WITH IO, UTIL,ADAGRAPH;
PACKAGE BODY AGTEST1 IS
USE IO, UTIL, ADAGRAPH;
--
--THIS PROGRAM DRAWS A TEST PATTERN TO TEST COLOR SELECTION,
--CURSOR SETTING, CIRCLE DRAWING, LINE DRAWING, AREA FILLING,
--AND BOUNDARY FILLING
--
x_pos, y_pos : integer;
quit : character;
begin
   CLS;
   x_pos := 320;
   y_pos := 108;
        color(5);    --GREEN
        set_curs(300, 135);
        color(3);    --BLUE
--DRAW A CIRCLE
        circle(300, 102, 142);
        color(6);    --RED
-- DRAW A RECTANGLE
        draw_line(158, 31, 442, 31);
        draw_line(442, 31, 442, 173);
        draw_line(442, 173, 158, 173);
        draw_line(158, 173, 158, 31);
--DRAW A CIRCLE AND FILL IT
        circle(300, 102, 40);
        area_fill(300,102,3);
--DRAW AN IRREGULAR POLYGON AND FILL IT
        draw_line(20,20,80,22);
        draw_line(80,22,84,50);
        draw_line(84,50,17,43);
        draw_line(17,43,20,20);
        boundary_fill(50,35,6,6);
--DRAW A TRIANGLE AND FILL IT
        draw_line(50,100,80,130);
        draw_line(80,130,20,130);
        draw_line(50,100,20,130);
        area_fill(50,120,5);
        color(2);    --MAGENTA
--DRAW A RECTANGLE
        draw_line(10, 10, 590, 10);
        draw_line(590, 10, 590, 205);
        draw_line(590, 205, 10, 205);
        draw_line(10, 205, 10, 10);
        color(5);
--DRAW A RECTANGLE WITH DIAGONAL LINES
        draw_line(200, 52, 400, 52);
        draw_line(400, 52, 400, 152);
        draw_line(400, 152, 200, 152);
        draw_line(200, 152, 200, 52);
        draw_line(200, 52, 400, 152);
        draw_line(200, 152, 400, 52);
        get(quit);
end AGTEST1;
```

APPENDIX C

GRAPHICS TEST 2

```
WITH IO, UTIL,ADAGRAPH;
PACKAGE BODY AGTEST2 IS
USE IO, UTIL, ADAGRAPH;
--
--THIS PROGRAM EXERCISES THE LINE DRAWING, CIRCLE,
--AND AREA FILLING PROCEDURES TO PRODUCE A PICTURE
--WITH COLORED CURVES AND A COLOR WHEEL
--
i, x, y, y1, y2, pcol : integer;
quit : character;
begin
  CLS;
  y := 0;
  y1 := 0;
  color(6);
--LOOP TO DRAW CURVE 1
  for i in 0..63 loop
    x := i * 10;
    y2 := 189 - y1;
    draw_mline(x, y, 0, y2);
    y := y + 2;
    y1 := y1 + 3;
  end loop;
  y := 0;
  y1 := 0;
  color(1);
--LOOP TO DRAW CURVE 2
  for i in 0..63 loop
    x := 630 - (i * 10);
    y2 := 189 - y1;
    draw_mline(x, y, 630, y2);
    y := y + 2;
    y1 := y1 + 3;
  end loop;
--DRAW A COLOR WHEEL
  color(0);  --WHITE
  circle(320, 150, 100);
  draw_line(320, 100, 320, 200);
  draw_line(220, 150, 420, 150);
  draw_line(249, 115, 391, 185);
  draw_line(391, 115, 249, 185);
  area_fill(355, 115, 0);  --COLOR 0 = WHITE
  area_fill(391, 140, 1);  --COLOR 1 = CYAN
  area_fill(391, 170, 2);  --COLOR 2 = MAGENTA
  area_fill(330, 185, 3);  --COLOR 3 = BLUE
  area_fill(310, 185, 4);  --COLOR 4 = YELLOW
  area_fill(249, 160, 5);  --COLOR 5 = GREEN
  area_fill(249, 130, 6);  --COLOR 6 = RED
  get(quit);
end AGTEST2;
```

APPENDIX D

GRAPHICS TEST 3

```
WITH IO, UTIL,ADAGRAPH;
PACKAGE BODY AGTEST3 IS
USE IO, UTIL, ADAGRAPH;
--
--THIS PROGRAM IS USED TO TEST SETTING AND RESETTING
--OF A GRAPHICS CURSOR.  THE PROGRAM REQUESTS CURSOR
--POSITION INPUTS, ERASES THE PREVIOUS CURSOR, AND
--DRAWS A CURSOR AT THE INPUT (X,Y) COORDINATE
--
i : integer;
x_pos, y_pos, x_old, y_old : integer;
begin
   CLS;
   x_old := 0;    --INITIALIZE X & Y
   y_old := 0;
   for i in 1..50 loop
         put("ENTER X POSITION ");
         get(x_pos);
         put("ENTER Y POSITION ");
         get(y_pos);
         color(5);   --GREEN
         reset_curs(x_old, y_old);
         set_curs(x_pos, y_pos);
         x_old := x_pos;
         y_old := y_pos - 18;
   end loop;
end AGTEST3;
```

APPENDIX E

GRAPHICS TEST 4

```
WITH IO, UTIL,ADAGRAPH;
PACKAGE BODY AGTEST4 IS
USE IO, UTIL, ADAGRAPH;
--THIS PROGRAM IS USED TO DISPLAY A CIRCLE OF THE APPROXIMATE
--MAXIMUM AREA THAT CAN BE FILLED BY A SINGLE CALL TO ONE OF
--THE FILL ROUTINES.  IT THEN DEMONSTRATES FILLING AND
--DRAWING OF POLYGONS USING ONLY THE SET_PIXEL AND RESET_PIXEL
--PROCEDURES.
x, y :INTEGER;
quit : character;
begin
  CLS;
--SELECT COLOR
      color(0);   --WHITE
--DRAW A CIRCLE
      circle(300, 102, 115);
--FILL THE CIRCLE WITH RED
      boundary_fill(300, 102, 6, 0);
color(1);  --CYAN
--DRAW A RECTANGLE USING SET PIXEL
for x in 250..350 loop
  set_pixel(x, 77);
  set_pixel(x, 127);
end loop;
for y in 77..127 loop
  set_pixel(250, y);
  set_pixel(350, y);
end loop;
--FILL THE RECTANGLE
area_fill(300, 102, 5);  --COLOR 5 = GREEN
--ERASE A RECTANGLE USING RESET PIXEL
for x in 280..320 loop
  for y in 92..112 loop
    reset_pixel(x, y);
  end loop;
end loop;
area_fill(375, 102, 2);
color(6);
      get(quit);
end AGTEST4;
```

APPENDIX F

SPECIFICATION PACKAGE

```
PACKAGE ADAGRAPH IS
   --RETURN ADDRESS VARIABLES
      RET_ADJ_SL,RET_RVA,RET_LS,RET_IC,RET_XM: INTEGER;
      RET_FILL,RET_AFILL,RET_OL,RET_SPE,RET_CPE:INTEGER;
      RET_DML,RET_RPE:INTEGER;
   --CURSOR ADDRESS VARIABLES
      CURS_0,CURS_1,CURS_2,CURS_3,CURS_4: INTEGER;
      X_LOC: INTEGER;
   --X/Y POSITION AND GENERAL PURPOSE VARIABLES
      X_START,Y_START,X_END,Y_END: INTEGER;
      X_POS,Y_POS,DELTA_X,DELTA_Y,INC_CTR: INTEGER;
      I_ERROR,END_CNT: INTEGER;
      X_CTR,Y_CTR,RADIUS,X_REL,Y_REL,P_VAL:INTEGER;
   --COLOR VARIABLES
      P_COLOR,F_COLOR,B_COLOR:INTEGER;
   --SYSTEM STATUS
      SYS_STAT: INTEGER;
   --SEGMENT E STATUS
      SEGMENT_E,SEGMENT_FE,SEGMENT_IE: INTEGER;
   --COLOR PLANE BASE ADDRESS
      COL_PL_ADDR: INTEGER;
      SAV_COL1_STAT,SAV_COL2_STAT,SAV_COL3_STAT: INTEGER;
      COL_PL1,COL_PL2,COL_PL3: INTEGER;
   --FILL ROUTINE CONTOL VARIABLE
      COL_MIX: INTEGER;
   --GRAPHICS LIBRARY PROCEDURES
   --
      PROCEDURE CLS;
      PROCEDURE COLOR(color_code : in INTEGER);
      PROCEDURE SET_CURS(x_pos, y_pos : in INTEGER);
      PROCEDURE RESET_CURS(x_pos, y_pos : in INTEGER);
      PROCEDURE DRAW_LINE(x_start, y_start, x_end, y_end : in INTEGER);
      PROCEDURE DRAW_MLINE(x_start, y_start, x_end, y_end : in INTEGER);
      PROCEDURE CIRCLE(x_ctr, y_ctr, radius : in INTEGER);
      PROCEDURE INQUIRE_COLOR(x_pos, y_pos : in INTEGER;
                              color : out INTEGER);
      PROCEDURE BOUNDARY_FILL(x_pos, y_pos, f_color, b_color :
                              in INTEGER);
      PROCEDURE AREA_FILL(x_pos, y_pos, f_color : in INTEGER);
      PROCEDURE SET_PIXEL(x_pos, y_pos : in INTEGER);
      PROCEDURE RESET_PIXEL(x_pos, y_pos : in INTEGER);
END ADAGRAPH;
```

APPENDIX G

ASSEMBLY CODE LISTING

```
 PACKAGE ASSEMBLY ADAGRAPH
            JMP        MAIN
;*******************************************************************
;*******************************************************************
;PROCEDURE CLS IS USED TO PERFORM A CLEAR SCREEN OPERATION
PROC CLS;
            PUSH       AX
            IN         AL, 0D8H       ;SAVE VIDEO STATUS
            PUSH       AX
            MOV        AL,0FH
            OUT        0D8H, AL       ;BLANK THE SCREEN
            IN         AL, 0DBH
            AND        AL, 0F7H
            OUT        0DBH, AL       ;SET BIT 3 = 0
            IN         AL, 0D9H
            AND        AL, 0F7H
            OUT        0D9H, AL       ;ENABLE CLRSCRN SIGNAL
            MOV        CX, 6680       ;INIT COUNTER FOR TIME DELAY
DELAY:      NOP                       ;TIME DELAY TO ALLOW VIDEO PROCESSOR
            LOOP       DELAY          ;TIME TO CLEAR VIDEO MEMORY
            IN         AL, 0D9H
            OR         AL, 08H
            OUT        0D9H, AL       ;DISABLE CLRSCRN SIGNAL
            POP        AX
            OUT        0D8H, AL       ;RESTORE SYSTEM STATUS
            POP        AX
            RET
END PROC CLS;
;*******************************************************************
;*******************************************************************
;PROCEDURE COLOR IS USED TO ENABLE COLOR PLANES TO PROVIDE THE SELECTED
;COLOR AND THE E SEGMENT REGISTER IS INITIALIZED TO ALLOW WRITING TO
;THE ENABLED COLOR PLANES.
PROC COLOR;
            POP        DX             ;SAVE RETURN ADDRESS
            POP        AX             ;GET COLOR CODE
            PUSH       DX             ;RESTORE RETURN ADDRESS
            AND        AX, 7          ;MASK COLOR CODE TO SET STATUS FLAGS
            JNZ        COLOR1
            MOV        [COL_PL1], 0C000H  ;COLOR IS WHITE
            MOV        [COL_PL2], 0D000H
            MOV        [COL_PL3], 0E000H
            JMP        EXIT_COL
COLOR1:     SUB        AL, 1
            JNZ        COLOR2
            MOV        [COL_PL1], 0C000H  ;COLOR IS CYAN
            MOV        [COL_PL2], 0E000H
            MOV        [COL_PL3], 0E000H
            JMP        EXIT_COL
COLOR2:     SUB        AL, 1
            JNZ        COLOR3
            MOV        [COL_PL1], 0C000H  ;COLOR IS MAGENTA
            MOV        [COL_PL2], 0D000H
            MOV        [COL_PL3], 0D000H
            JMP        EXIT_COL
COLOR3:     SUB        AL, 1
            JNZ        COLOR4
            MOV        [COL_PL1], 0C000H  ;COLOR IS BLUE
            MOV        [COL_PL2], 0C000H
            MOV        [COL_PL3], 0C000H
            JMP        EXIT_COL
```

```
COLOR4:     SUB     AL, 1
            JNZ     COLOR5
            MOV     [COL_PL1], 0D000H  ;COLOR IS YELLOW
            MOV     [COL_PL2], 0E000H
            MOV     [COL_PL3], 0E000H
            JMP     EXIT_COL
COLOR5:     SUB     AL, 1
            JNZ     COLOR6
            MOV     [COL_PL1], 0E000H  ;COLOR IS GREEN
            MOV     [COL_PL2], 0E000H
            MOV     [COL_PL3], 0E000H
            JMP     EXIT_COL
COLOR6:     SUB     AL, 1
            JNZ     EXIT_COL
            MOV     [COL_PL1], 0D000H  ;COLOR IS RED
            MOV     [COL_PL2], 0D000H
            MOV     [COL_PL3], 0D000H
            JMP     EXIT_COL
EXIT_COL:   MOV     AL, 78H            ;DISABLE SIMULTANEOUS WRITE
            OUT     0D8H, AL
            RET
END PROC COLOR;
;**********************************************************************
;**********************************************************************
;PROCEDURE RESET_CURS IS USED TO ERASE THE GRAPHICS CURSOR
;AN (X,Y) POSITION IS INPUT TO THE PROCEDURE AND THE A BLOCK OF
;ADDRESSES IS CLEARED AT THE CURSOR LOCATION
PROC RESET_CURS;
            MOV     [SEGMENT_E], ES    ;SAVE SEG E STATUS
            POP     AX              ;SAVE RETURN ADDRESS
            POP     [Y_POS]         ;GET Y POSITION
            POP     [X_POS]         ;GET X POSITION
            PUSH    AX              ;RESTORE RETURN ADDRESS
            PUSH    [X_POS]
            PUSH    [Y_POS]
            CALL    ADJ_SL          ;ADJUST Y POSITION TO A DISPLAYABLE
            CALL    REL_VID_ADDR    ;SCAN LINE & GET VIDEO ADDRESS
            POP     BX
            CALL    BLANK_GCURS
            SUB     BX, 1
            CALL    BLANK_GCURS
            SUB     [Y_POS], 1
            PUSH    [X_POS]
            PUSH    [Y_POS]
            CALL    ADJ_SL
            CALL    REL_VID_ADDR
            POP     BX
            CALL    BLANK_GCURS
            SUB     [Y_POS], 1
            PUSH    [X_POS]
            PUSH    [Y_POS]
            CALL    ADJ_SL
            CALL    REL_VID_ADDR
            POP     BX
            CALL    BLANK_GCURS
            ADD     [Y_POS], 3
            PUSH    [X_POS]
            PUSH    [Y_POS]
            CALL    ADJ_SL
            CALL    REL_VID_ADDR
            POP     BX
            CALL    BLANK_GCURS
            ADD     [Y_POS], 1
            PUSH    [X_POS]
            PUSH    [Y_POS]
            CALL    ADJ_SL
            CALL    REL_VID_ADDR
            POP     BX
            CALL    BLANK_GCURS
```

```
            MOV       ES, [SEGMENT_E]  ;RESTORE SEG E
            RET
END PROC RESET_CURS;
;*****************************************************************
;*****************************************************************
;PROCEDURE BLANK_GCURS IS USED BY PROCEDURE RESET_CURS TO ERASE A CURSOR
PROC BLANK_GCURS;
            MOV       AX, [COL_PL1]
            MOV       ES, AX
            SEG       ES
            MOV       [BX], 0
            MOV       AX, [COL_PL2]
            MOV       ES, AX
            SEG       ES
            MOV       [BX], 0
            MOV       AX, [COL_PL3]
            MOV       ES, AX
            SEG       ES
            MOV       [BX], 0
            RET
END PROC BLANK_GCURS;
;*****************************************************************
;*****************************************************************
;PROCEDURE SET_CURS IS USED TO DISPLAY A CURSOR AT THE INPUT
;(X,Y) POSITION.  THE GRAPHICS CURSOR DISPLAYED IS A "+".
PROC SET_CURS;
;CALCULATE MEMORY ADDRESS OF NEW CURSOR POSITION
            MOV       [SEGMENT_E], ES   ;SAVE SEG E STATUS
            POP       AX              ;SAVE RETURN ADDRESS
            POP       [Y_POS]         ;GET Y POSITION FROM STACK
            POP       [X_POS]         ;GET X POSITION FROM STACK
            PUSH      AX              ;REPLACE RETURN ADDRESS
            MOV       DX, [Y_POS]
            PUSH      [Y_POS]
            CALL      ADJ_SL
            POP       BX              ;GET CORRECTED Y LINE NUMBER
;
;THE CURSOR IS MADE UP OF FIVE COMPONENTS LABELED CURS_0 TO CURS_4
            MOV       [CURS_0], DX  ;PUT THE LINE NUMBER INTO
            MOV       [CURS_1], DX  ;EACH OF THE CURSOR ROWS
            MOV       [CURS_2], BX
            MOV       [CURS_3], DX
            MOV       [CURS_4], DX
            SUB       [CURS_0], 2
            MOV       AX, [CURS_0]
            JNS       C0
            MOV       AX, 3
            ADD       [CURS_0], AX  ;ADJUST EACH CURSOR ROW TO REFLECT IT
C0:         PUSH      [CURS_0]      ;DISTANCE FROM CURSOR CENTER POSITION
            CALL      ADJ_SL        ;WHICH IS CURS_2
            POP       [CURS_0]      ;THEN CALL PROCEDURE ADJ_SL TO ASSURE
            SUB       [CURS_1], 1   ;THAT EACH CURSOR ROW IS LOCATED ON
            MOV       AX, [CURS_1]  ;A DISPLAYABLE SCAN LINE
            JNS       C1
            ADD       [CURS_1], 2
C1:         PUSH      [CURS_1]
            CALL      ADJ_SL
            POP       [CURS_1]
            ADD       [CURS_3], 1
            PUSH      [CURS_3]
            CALL      ADJ_SL
            POP       [CURS_3]
            ADD       [CURS_4], 2
            PUSH      [CURS_4]
            CALL      ADJ_SL
            POP       [CURS_4]
            PUSH      [X_POS]
            PUSH      BX
            CALL      REL_VID_ADDR
```

```
                POP     BX
                PUSH    [X_POS]
                PUSH    [CURS_0]
                CALL    REL_VID_ADDR
                POP     [CURS_0]
                PUSH    [X_POS]
                PUSH    [CURS_1]
                CALL    REL_VID_ADDR
                POP     [CURS_1]
                PUSH    [X_POS]
                PUSH    [CURS_2]
                CALL    REL_VID_ADDR
                POP     [CURS_2]
                PUSH    [X_POS]
                PUSH    [CURS_3]
                CALL    REL_VID_ADDR
                POP     [CURS_3]
                PUSH    [X_POS]
                PUSH    [CURS_4]
                CALL    REL_VID_ADDR
                POP     [CURS_4]
                MOV     AX, [X_POS]     ;GET X POSITION FOR TEST
                AND     AX, 07H        ;CALCULATE CURSOR BIT POSITION IN ADDR
;
;DRAW THE CURSOR BASED ON CURSOR CENTER BIT POSITION WITHIN A BYTE
;THIS SPLITS THE CURSOR ACROSS BYTE BOUNDARIES FOR FULL SCREEN COVERAGE
                JNZ     BIT1            ;TEST FOR CURSOR IN X PIXEL POS. 0
                MOV     AL, 3
                MOV     BX, [CURS_2]
                SUB     BX, 1
                CALL    DISP_GCURS
                MOV     AL, 0E0H
                ADD     BX, 1
                CALL    DISP_GCURS
                MOV     AL, 80H
                MOV     BX, [CURS_0]
                CALL    DISP_GCURS
                MOV     BX, [CURS_1]
                CALL    DISP_GCURS
                MOV     BX, [CURS_3]
                CALL    DISP_GCURS
                MOV     BX, [CURS_4]
                CALL    DISP_GCURS
                JMP     EXIT
BIT1:           SUB     AL, 1           ;DECREMENT BIT COUNT FOR NEXT TEST
                JNZ     BIT2            ;TEST FOR CURSOR IN X PIXEL POS. 1
                MOV     BX, [CURS_2]
                SUB     BX, 1
                MOV     AL, 1
                CALL    DISP_GCURS
                MOV     AL, 0F0H
                ADD     BX, 1
                CALL    DISP_GCURS
                MOV     AL, 40H
                MOV     BX, [CURS_0]
                CALL    DISP_GCURS
                MOV     BX, [CURS_1]
                CALL    DISP_GCURS
                MOV     BX, [CURS_3]
                CALL    DISP_GCURS
                MOV     BX, [CURS_4]
                CALL    DISP_GCURS
                JMP     EXIT
BIT2:           SUB     AL, 1           ;DECREMENT BIT COUNT FOR NEXT TEST
                JNZ     BIT3            ;TEST FOR CURSOR IN X PIXEL POS. 2
                MOV     AL, 0F8H
                MOV     BX, [CURS_2]
                CALL    DISP_GCURS
                MOV     AL, 20H
```

```
          MOV     BX, [CURS_0]
          CALL    DISP_GCURS
          MOV     BX, [CURS_1]
          CALL    DISP_GCURS
          MOV     BX, [CURS_3]
          CALL    DISP_GCURS
          MOV     BX, [CURS_4]
          CALL    DISP_GCURS
          JMP     EXIT
BIT3:     SUB     AL, 1           ;DECREMENT BIT COUNT FOR NEXT TEST
          JNZ     BIT4            ;TEST FOR CURSOR IN X PIXEL POS. 3
          MOV     AL, 7CH
          MOV     BX, [CURS_2]
          CALL    DISP_GCURS
          MOV     AL, 10H
          MOV     BX, [CURS_0]
          CALL    DISP_GCURS
          MOV     BX, [CURS_1]
          CALL    DISP_GCURS
          MOV     BX, [CURS_3]
          CALL    DISP_GCURS
          MOV     BX, [CURS_4]
          CALL    DISP_GCURS
          JMP     EXIT
BIT4:     SUB     AL, 1           ;DECREMENT BIT COUNT FOR NEXT TEST
          JNZ     BIT5            ;TEST FOR CURSOR IN X PIXEL POS. 4
          MOV     AL, 3EH
          MOV     BX, [CURS_2]
          CALL    DISP_GCURS
          MOV     AL, 8
          MOV     BX, [CURS_0]
          CALL    DISP_GCURS
          MOV     BX, [CURS_1]
          CALL    DISP_GCURS
          MOV     BX, [CURS_3]
          CALL    DISP_GCURS
          MOV     BX, [CURS_4]
          CALL    DISP_GCURS
          JMP     EXIT
BIT5:     SUB     AL, 1           ;DECREMENT BIT COUNT FOR NEXT TEST
          JNZ     BIT6            ;TEST FOR CURSOR IN X PIXEL POS. 5
          MOV     AL, 1FH
          MOV     BX, [CURS_2]
          CALL    DISP_GCURS
          MOV     AL, 4
          MOV     BX, [CURS_0]
          CALL    DISP_GCURS
          MOV     BX, [CURS_1]
          CALL    DISP_GCURS
          MOV     BX, [CURS_3]
          CALL    DISP_GCURS
          MOV     BX, [CURS_4]
          CALL    DISP_GCURS
          JMP     EXIT
BIT6:     SUB     AL, 1           ;DECREMENT BIT COUNT FOR NEXT TEST
          JNZ     BIT7            ;TEST FOR CURSOR IN X PIXEL POS. 6
          MOV     AL, 0FH
          MOV     BX, [CURS_2]
          CALL    DISP_GCURS
          MOV     AL, 80H
          ADD     BX, 1
          CALL    DISP_GCURS
          MOV     AL, 2
          MOV     BX, [CURS_0]
          CALL    DISP_GCURS
          MOV     BX, [CURS_1]
          CALL    DISP_GCURS
          MOV     BX, [CURS_3]
          CALL    DISP_GCURS
```

```
                MOV       BX, [CURS_4]
                CALL      DISP_GCURS
                JMP       EXIT
BIT7:           MOV       AL, 7
                MOV       BX, [CURS_2]
                CALL      DISP_GCURS
                MOV       AL, 0C0H
                ADD       BX, 1
                CALL      DISP_GCURS
                MOV       AL, 1
                MOV       BX, [CURS_0]
                CALL      DISP_GCURS
                MOV       BX, [CURS_1]
                CALL      DISP_GCURS
                MOV       BX, [CURS_3]
                CALL      DISP_GCURS
                MOV       BX, [CURS_4]
                CALL      DISP_GCURS
EXIT:           MOV       ES, [SEGMENT_E]   ;RESTORE SEG E
                RET
END PROC SET_CURS;
;*********************************************************************
;*********************************************************************
;PROCEDURE DISP_GCURS IS USED BY PROCEDURE SET_CURS TO DISPLAY A CURSOR
PROC DISP_GCURS;
                MOV       DX, [COL_PL1]
                MOV       ES, DX
                SEG       ES
                OR        [BX], AL
                MOV       DX, [COL_PL2]
                MOV       ES, DX
                SEG       ES
                OR        [BX], AL
                MOV       DX, [COL_PL3]
                MOV       ES, DX
                SEG       ES
                OR        [BX], AL
                RET
END PROC DISP_GCURS;
;*********************************************************************
;*********************************************************************
;PROCEDURE ADJ_SL IS USED TO CORRECT Y POSITION TO INSURE
;THAT IT OCCURS ON A DISPLAYABLE SCAN LINE
PROC ADJ_SL;
                POP       [RET_ADJ_SL]    ;SAVE RETURN ADDRESS
                POP       BX              ;GET Y POSITION
                MOV       AX, BX
TST_Y:          SUB       AX, 9
                JNS       ADJ_Y
                JMP       EXIT_SL
ADJ_Y:          ADD       BX, 7
                JMP       TST_Y
EXIT_SL:        PUSH      BX              ;RETURN CORRECTED Y POSITION
                PUSH      [RET_ADJ_SL]    ;RESTORE RETURN ADDRESS
                RET
END PROC ADJ_SL;
;*********************************************************************
;*********************************************************************
;PROCEDURE REL_VID_ADDR ACCEPTS X AND Y SCREEN COORDINATES AND CONVERTS
;THEM TO A BYTE ADDRESS IN MEMORY CORRESPONDING TO THE X Y POSITION
PROC REL_VID_ADDR;
                POP       [RET_RVA]       ;SAVE RETURN ADDRESS
                POP       BX              ;GET Y POSITION
                TEST      BX, 8000H       ;TEST FOR Y < 0
                JNS       TST_YUPR
                MOV       BX, 0
TST_YUPR:       MOV       AX, 376         ;TEST FOR Y > 376
                SUB       AX, BX
                JNS       Y_IN_BND
```

```
            MOV         BX, 376
Y_IN_BND:   MOV         AX, 80H          ;PUT SCALE FACTOR IN AX
            MUL         BX               ;AND SCALE Y BASED ON LINE NUMBER
            POP         BX               ;GET X POSITION
            TEST        BX, 8000H        ;TEST FOR X < 0
            JNS         TST_XUPR
            MOV         BX, 0
TST_XUPR:   MOV         DX, 639          ;TEST FOR X > 639
            SUB         DX, BX
            JNS         X_IN_BND
            MOV         BX, 639
X_IN_BND:   MOV         CL, 3            ;AND DETERMINE BYTE X OFFSET
            SHR         BX, CL           ;BY DIVIDING X POSITION BY 8
            ADD         BX, AX           ;ADD X OFFSET TO GET BYTE ADDRESS
            PUSH        BX               ;RETURN RELATIVE BYTE ADDRESS
            PUSH        [RET_RVA]        ;RESTORE RETURN ADDRESS
            RET
END PROC REL_VID_ADDR;
;*********************************************************************
;*********************************************************************
;LINE DRAWING PROCEDURE WITH COLOR MIXING FOR CROSSING LINES
PROC DRAW_MLINE;
            POP         [RET_DML]        ;SAVE RETURN ADDRESS
            MOV         [COL_MIX], 1     ;ENABLE COLOR MIXING
            CALL        DRAWW_LINE       ;GO DRAW THE LINE
            PUSH        [RET_DML]        ;RESTORE RETURN ADDRESS
            RET
END PROC DRAW_MLINE;
;*********************************************************************
;*********************************************************************
;LINE DRAWING PROCEDURE WITHOUT COLOR MIXING FOR CROSSING LINES
PROC DRAW_LINE;
            POP         [RET_DML]        ;SAVE RETURN ADDRESS
            MOV         [COL_MIX], 0     ;DISABLE COLOR MIXING
            CALL        DRAWW_LINE       ;GO DRAW THE LINE
            PUSH        [RET_DML]        ;RESTORE RETURN ADDRESS
            RET
END PROC DRAW_LINE;
;*********************************************************************
;*********************************************************************
;PROCEDURE DRAWW_LINE PROVIDES PRIMITIVE LINE DRAWING CAPABILITIES
;THE SUBROUTINE ACCEPTS AS INPUT A PAIR OF ENDPOINTS IDENTIFIED BY
;(X, Y) COORDINATES
PROC DRAWW_LINE;
            MOV          BP, SP
            PUSH         DS
            MOV          BX, [BP+8]         ;GET X START FROM STACK
            MOV          [X_START], BX
            MOV          BX, [BP+6]         ;GET Y START FROM STACK
            MOV          [Y_START], BX
            MOV          BX, [BP+4]         ;GET X END FROM STACK
            MOV          [X_END], BX
            MOV          AX, [BP+2]         ;GET Y END FROM STACK
            MOV          [Y_END], AX
;TEST ORDERING OF Y COORDINATES.  THE ALGORITHM EXPECTS TO FIND THE Y
;COORDINATE IN INCREASING ORDER OR 0.
            MOV          AX, [Y_END]
            SUB          AX, [Y_START]
            JNS          STO_DY             ;JUMP IF Y ORDERING OK
            MOV          AX, [X_START]      ;ELSE SWAP START AND END COORD.
            MOV          BX, [X_END]        ;SO Y START VALUE IS LTE Y END
            MOV          [X_START], BX      ;VALUE.  THEN CALCULATE DELTA Y.
            MOV          [X_END], AX
            MOV          AX, [Y_START]
            MOV          BX, [Y_END]
            MOV          [Y_START], BX
            MOV          [Y_END], AX
            SUB          AX, BX
STO_DY:     MOV          [DELTA_Y], AX
```

```
        MOV     AX, [X_END]        ;CALCULATE DELTA X
        SUB     AX, [X_START]
        MOV     [DELTA_X], AX
        MOV     [INC_CTR], 1
        MOV     [L_ERROR], 0
        MOV     AX, [X_START]
        MOV     [X_POS], AX
        MOV     AX, [Y_START]
        MOV     [Y_POS], AX
        PUSH    [X_POS]
        PUSH    [Y_POS]
        CALL    LINE_SEG           ;PLOT FIRST POINT
        TEST    [DELTA_X], 8000H   ;TEST FOR NEGATIVE SLOPE
        JNS     TST_DY
        JMP     TST_DYZ
TST_DY: TEST    [DELTA_Y], 7FFFH   ;TEST FOR DELTA Y = 0
        JNZ     C_2_OR_3
        SUB     [DELTA_X], 1
CASE_1: ADD     [X_POS], 1         ;DRAW LINE FOR SPECIAL CASE WHERE
        PUSH    [X_POS]            ;DX > 0 AND DY = 0
        PUSH    [Y_POS]
        CALL    LINE_SEG
        SUB     [DELTA_X], 1
        JNS     CASE_2
        JMP     EXIT_DL
C_2_OR_3: MOV   AX, [DELTA_X]      ;DX > 0 AND DY > 0
        SUB     AX, [DELTA_Y]
        JNS     CASE_2
        JMP     CASE_3
CASE_2: MOV     AX, [DELTA_X]      ;DX >= DY
        MOV     [END_CNT], AX
;
        MOV     BX, [DELTA_Y]      ;ADD IN CORRECTION FACTOR FOR
        ADD     BX, 1              ;SMOOTHING
        JNZ     C_CASE2            ;CORR = DX/(DY+1)
        JMP     DR_C2
C_CASE2: MOV    AX, [DELTA_X]
        MOV     DX, 0
        DIV     BX
        SUB     [L_ERROR], AX      ;INIT ERROR VAL. WITH CORR. FACT.
;
DR_C2:  MOV     AX, [END_CNT]      ;TEST INCREMENT COUNTER
        SUB     AX, [INC_CTR]
        JNS     DR_C2C
        JMP     EXIT_DL
DR_C2C: TEST    [L_ERROR], 8000H   ;TEST IF ERROR < 0
        JNS     CASE_2C
        ADD     [X_POS], 1         ;ERROR < 0
        PUSH    [X_POS]
        PUSH    [Y_POS]
        CALL    LINE_SEG
        MOV     AX, [L_ERROR]
        ADD     AX, [DELTA_Y]
        MOV     [L_ERROR], AX
        ADD     [INC_CTR], 1
        JMP     DR_C2
CASE_2C: ADD    [X_POS], 1         ;ERROR >= 0
        ADD     [Y_POS], 1
        PUSH    [X_POS]
        PUSH    [Y_POS]
        CALL    LINE_SEG
        MOV     AX, [L_ERROR]
        ADD     AX, [DELTA_Y]
        SUB     AX, [DELTA_X]
        MOV     [L_ERROR], AX
        ADD     [INC_CTR], 1
        JMP     DR_C2
CASE_3: MOV     AX, [DELTA_Y]      ;DY > DX
        MOV     [END_CNT], AX
```

```
;
            MOV     BX, [DELTA_X]       ;ADD IN CORRECTION FACTOR FOR
            ADD     BX, 1               ;SMOOTHING
            JNZ     C_CASE3             ;CORR = DY/(DX+1)
            JMP     DR_C3
C_CASE3:    MOV     AX, [DELTA_Y]
            MOV     DX, 0
            DIV     BX
            MOV     [L_ERROR], AX       ;INIT ERROR VAL. WITH CORR. FACT.
;
DR_C3:      MOV     AX, [END_CNT]       ;TEST INCREMENT COUNTER
            SUB     AX, [INC_CTR]
            JNS     DR_C3C
            JMP     EXIT_DL
DR_C3C:     TEST    [L_ERROR], 8000H ;TEST FOR ERROR < 0
            JNS     CASE_3C
            ADD     [X_POS], 1          ;ERROR < 0
            ADD     [Y_POS], 1
            PUSH    [X_POS]
            PUSH    [Y_POS]
            CALL    LINE_SEG
            MOV     AX, [L_ERROR]
            SUB     AX, [DELTA_X]
            ADD     AX, [DELTA_Y]
            MOV     [L_ERROR], AX
            ADD     [INC_CTR], 1
            JMP     DR_C3
CASE_3C:    ADD     [Y_POS], 1          ;ERROR >= 0
            PUSH    [X_POS]
            PUSH    [Y_POS]
            CALL    LINE_SEG
            MOV     AX, [L_ERROR]
            SUB     AX, [DELTA_X]
            MOV     [L_ERROR], AX
            ADD     [INC_CTR], 1
            JMP     DR_C3
TST_DYZ:    TEST    [DELTA_Y], 7FFFH ;TEST FOR DY > 0
            JNZ     C_5_OR_6
            MOV     AX, 0FFFFH        ;PROCESS SPECIAL CASE WHERE DX < 0
            SUB     AX, [DELTA_X]       ;AND DY = 0
            MOV     [DELTA_X], AX
CASE_4:     SUB     [X_POS], 1
            PUSH    [X_POS]
            PUSH    [Y_POS]
            CALL    LINE_SEG
            SUB     [DELTA_X], 1
            JNS     CASE_4
            JMP     EXIT_DL
C_5_OR_6:   MOV     AX, 0               ;CASE 3 OR 4.  DX < 0 & DY > 0
            SUB     AX, [DELTA_X]
            SUB     AX, [DELTA_Y]
            JNS     CASE_5
            JMP     CASE_6
CASE_5:     MOV     AX, 0               ;DY <= ABS(DX)
            SUB     AX, [DELTA_X]
            MOV     [END_CNT], AX
;
            MOV     BX, [DELTA_Y]       ;ADD IN CORRECTION FACTOR FOR
            ADD     BX, 1               ;SMOOTHING
            JNZ     C_CASE5             ;CORR = DX/(DY+1)
            JMP     DR_C5
C_CASE5:    MOV     AX, 0
            SUB     AX, [DELTA_X]
            MOV     DX, 0
            DIV     BX
            SUB     [L_ERROR], AX       ;INIT ERROR WITH CORR. FACT.
;
DR_C5:      MOV     AX, [END_CNT]       ;TEST INCREMENT COUNTER
            SUB     AX, [INC_CTR]
```

```
            JNS     DR_C5C
            JMP     EXIT_DL
DR_C5C:     TEST    [L_ERROR], 8000H ;TEST IF ERROR < 0
            JNS     CASE_5C
            SUB     [X_POS], 1       ;ERROR < 0
            PUSH    [X_POS]
            PUSH    [Y_POS]
            CALL    LINE_SEG
            MOV     AX, [L_ERROR]
            ADD     AX, [DELTA_Y]
            MOV     [L_ERROR], AX
            ADD     [INC_CTR], 1
            JMP     DR_C5
CASE_5C:    SUB     [X_POS], 1       ;ERROR >= 0
            ADD     [Y_POS], 1
            PUSH    [X_POS]
            PUSH    [Y_POS]
            CALL    LINE_SEG
            MOV     AX, [L_ERROR]
            ADD     AX, [DELTA_X]
            ADD     AX, [DELTA_Y]
            MOV     [L_ERROR], AX
            ADD     [INC_CTR], 1
            JMP     DR_C5
CASE_6:     MOV     AX, [DELTA_Y]    ;ABS(DX) < DY
            MOV     [END_CNT], AX

            MOV     BX, 1            ;ADD IN CORRECTION FACTOR FOR
            SUB     BX, [DELTA_X]    ;SMOOTHING
            JNZ     C_CASE6          ;CORR = DY/(DX+1)
            JMP     DR_C6
C_CASE6:    MOV     AX, [DELTA_Y]
            MOV     DX, 0
            DIV     BX
            MOV     [L_ERROR], AX    ;INIT ERROR WITH CORR. FACT.

DR_C6:      MOV     AX, [END_CNT]    ;TEST INCREMENT COUNTER
            SUB     AX, [INC_CTR]
            JNS     DR_C6C
            JMP     EXIT_DL
DR_C6C:     TEST    [L_ERROR], 8000H ;TEST FOR ERROR < 0
            JNS     CASE_6C
            SUB     [X_POS], 1       ;ERROR < 0
            ADD     [Y_POS], 1
            PUSH    [X_POS]
            PUSH    [Y_POS]
            CALL    LINE_SEG
            MOV     AX, [L_ERROR]
            ADD     AX, [DELTA_X]
            ADD     AX, [DELTA_Y]
            MOV     [L_ERROR], AX
            ADD     [INC_CTR], 1
            JMP     DR_C6
CASE_6C:    ADD     [Y_POS], 1       ;ERROR >= 0
            PUSH    [X_POS]
            PUSH    [Y_POS]
            CALL    LINE_SEG
            MOV     AX, [L_ERROR]
            ADD     AX, [DELTA_X]
            MOV     [L_ERROR], AX
            ADD     [INC_CTR], 1
            JMP     DR_C6
EXIT_DL:    POP     DS               ;PREPARE TO EXIT PROCEDURE BY
            POP     AX               ;RESTORING REGISTERS AND THEN
            POP     BX               ;REMOVE INPUT PARAMETERS
            POP     BX               ;FROM STACK
            POP     BX
            POP     BX
            PUSH    AX
```

```
          RET
END PROC DRAWW_LINE;
;*****************************************************************
;*****************************************************************
;PROCEDURE LINE_SEG ACCEPTS AS INPUT AN X AND Y POSITION AND CONVERTS
;THE POSITION INTO DISPLAYABLE PIXEL DATA
PROC LINE_SEG;
          MOV       [SEGMENT_E], ES    ;SAVE SEG E STATUS
          MOV       ES, [COL_PL_ADDR] ;ENABLE SELECTED COLOR
          POP       [RET_LS]          ;SAVE RETURN ADDRESS
          CALL      ADJ_SL          ;CONVERT Y POS. TO DISPLAYABLE S.L.
          CALL      REL_VID_ADDR    ;USE X & Y TO CALC REL. BYTE ADDR.
          POP       BX              ;BX REGISTER HOLDS REL. BYTE ADDR.
          MOV       AX, [X_POS]     ;MOV X POSITION TO AX REGISTER AND
          AND       AX, 7           ;CALCULATE X BIT POSITION WITHIN A
          JNZ       XBIT1           ;BYTE FOR DISPLAY PURPOSES
          MOV       DL, 80H
          MOV       CL, 7FH
          JMP       OUT_LINE
XBIT1:    SUB       AL, 1
          JNZ       XBIT2
          MOV       DL, 40H
          MOV       CL, 0BFH
          JMP       OUT_LINE
XBIT2:    SUB       AL, 1
          JNZ       XBIT3
          MOV       DL, 20H
          MOV       CL, 0DFH
          JMP       OUT_LINE
XBIT3:    SUB       AL, 1
          JNZ       XBIT4
          MOV       DL, 10H
          MOV       CL, 0EFH
          JMP       OUT_LINE
XBIT4:    SUB       AL, 1
          JNZ       XBIT5
          MOV       DL, 8
          MOV       CL, 0F7H
          JMP       OUT_LINE
XBIT5:    SUB       AL, 1
          JNZ       XBIT6
          MOV       DL, 4
          MOV       CL, 0FBH
          JMP       OUT_LINE
XBIT6:    SUB       AL, 1
          JNZ       XBIT7
          MOV       DL, 2
          MOV       CL, 0FDH
          JMP       OUT_LINE
XBIT7:    MOV       DL, 1
          MOV       CL, 0FEH
OUT_LINE: CMP       [COL_MIX], 1    ;TEST IF MIXING ENABLED
          JNS       LSC_MIX
          MOV       AX, 0C000H      ;CLEAR SELECTED LOCATION IN ALL
          MOV       ES, AX          ;COLOR PLANES IF NO MIXING
          SEG       ES
          AND       [BX], CL
          MOV       AX, 0D000H
          MOV       ES, AX
          SEG       ES
          AND       [BX], CL
          MOV       AX, 0E000H
          MOV       ES, AX
          SEG       ES
          AND       [BX], CL
LSC_MIX:  MOV       AX, [COL_PL1]
          MOV       ES, AX
          SEG       ES              ;SELECT E SEGMENT FOR ADDRESSING OF
          OR        [BX], DL        ;VIDEO OUTPUT THEN OUTPUT A BYTE
```

```
                MOV         AX, [COL_PL2]
                MOV         ES, AX
                SEG         ES
                OR          [BX], DL
                MOV         AX, [COL_PL3]
                MOV         ES, AX
                SEG         ES
                OR          [BX], DL
                PUSH        [RET_LS]        ;RESTORE RETURN ADDRESS
                MOV         ES, [SEGMENT_E] ;RESTORE SEG E
                RET
END PROC LINE_SEG;
;*******************************************************************
;*******************************************************************
;PROCEDURE CIRCLE INPUTS X & Y COORDINATES OF THE CIRCLE CENTER
;AND A RADIUS VALUE.  IT THEN DRAWS A CIRCLE.
PROC CIRCLE;
                MOV         BP, SP
                MOV         AX, [BP+6]
                MOV         [X_CTR], AX     ;GET X CENTER COORDINATE OFF STACK
                MOV         AX, [BP+4]
                MOV         [Y_CTR], AX     ;GET Y CENTER COORDINATE OFF STACK
                MOV         DX, [BP+2]
                MOV         [Y_REL], DX     ;GET RADIUS VALUE AND SET
                MOV         [X_REL], 0      ;INITIAL VALUES FOR X AND Y COORD.
                MOV         CL, 1
                SHL         DX, CL
                MOV         AX, 3
                SUB         AX, DX
                MOV         [P_VAL], AX
CIRC_LP:        MOV         AX, [Y_REL]     ;TEST IF FINISHED DRAWING CIRCLE
                SUB         AX, [X_REL]
                JNS         DR_CIRC
                POP         AX
                POP         BX              ;REMOVE INPUT PARAMETERS FROM STACK
                POP         BX
                POP         BX
                PUSH        AX
                RET                         ;EXIT SUBROUTINE
;
;POINTS ON CIRCLE ARE PLOTTED IN GROUPS OF 8 WITH THE Y COORDINATE
;SCALED BY 1/2 TO COMPENSATE FOR X:Y RATIO IN THE DISPLAY
DR_CIRC:        MOV         AX, [X_CTR]     ;CALCULATE POINT 1
                MOV         DX, [X_REL]
                ADD         AX, DX
                MOV         [X_POS], AX
                PUSH        AX
                MOV         AX, [Y_REL]
                MOV         CL, 1
                SHR         AX, CL
                ADD         AX, [Y_CTR]
                PUSH        AX
                CALL        ADJ_SL
                POP         [Y_POS]
                PUSH        [Y_POS]
                CALL        REL_VID_ADDR
                PUSH        [X_POS]
                CALL        CIR_PIXEL        ;PLOT (X_CENTER+X, Y_CENTER+Y)
                MOV         AX, [X_CTR]      ;CALCULATE POINT 2
                MOV         DX, [X_REL]
                SUB         AX, DX
                MOV         [X_POS], AX
                PUSH        AX
                PUSH        [Y_POS]
                CALL        REL_VID_ADDR
                PUSH        [X_POS]
                CALL        CIR_PIXEL        ;PLOT (X_CENTER-X, Y_CENTER+Y)
                PUSH        [X_POS]          ;CALCULATE POINT 3
                MOV         BX, [Y_REL]
```

```
        MOV     CL, 1
        SHR     BX, CL
        MOV     AX, [Y_CTR]
        SUB     AX, BX
        PUSH    AX
        CALL    ADJ_SL
        POP     [Y_POS]
        PUSH    [Y_POS]
        CALL    REL_VID_ADDR
        PUSH    [X_POS]
        CALL    CIR_PIXEL           ;PLOT (X_CENTER-X, Y_CENTER-Y)
        MOV     AX, [X_CTR]         ;CALCULATE POINT 4
        MOV     DX, [X_REL]
        ADD     AX, DX
        MOV     [X_POS], AX
        PUSH    AX
        PUSH    [Y_POS]
        CALL    REL_VID_ADDR
        PUSH    [X_POS]
        CALL    CIR_PIXEL           ;PLOT (X_CENTER+X, Y_CENTER-Y)
        MOV     AX, [X_CTR]         ;CALCULATE POINT 5
        MOV     DX, [Y_REL]
        ADD     AX, DX
        MOV     [X_POS], AX
        PUSH    AX
        MOV     AX, [X_REL]
        MOV     CL, 1
        SHR     AX, CL
        ADD     AX, [Y_CTR]
        PUSH    AX
        CALL    ADJ_SL
        POP     [Y_POS]
        PUSH    [Y_POS]
        CALL    REL_VID_ADDR
        PUSH    [X_POS]
        CALL    CIR_PIXEL           ;PLOT (X_CENTER+Y, Y_CENTER+X)
        MOV     AX, [X_CTR]         ;CALCULATE POINT 6
        MOV     DX, [Y_REL]
        SUB     AX, DX
        MOV     [X_POS], AX
        PUSH    AX
        PUSH    [Y_POS]
        CALL    REL_VID_ADDR
        PUSH    [X_POS]
        CALL    CIR_PIXEL           ;PLOT (X_CENTER-Y, Y_CENTER+X)
        PUSH    [X_POS]             ;CALCULATE POINT 7
        MOV     BX, [X_REL]
        MOV     CL, 1
        SHR     BX, CL
        MOV     AX, [Y_CTR]
        SUB     AX, BX
        PUSH    AX
        CALL    ADJ_SL
        POP     [Y_POS]
        PUSH    [Y_POS]
        CALL    REL_VID_ADDR
        PUSH    [X_POS]
        CALL    CIR_PIXEL           ;PLOT (X_CENTER-Y, Y_CENTER-X)
        MOV     AX, [X_CTR]         ;CALCULATE POINT 8
        MOV     DX, [Y_REL]
        ADD     AX, DX
        MOV     [X_POS], AX
        PUSH    AX
        PUSH    [Y_POS]
        CALL    REL_VID_ADDR
        PUSH    [X_POS]
        CALL    CIR_PIXEL           ;PLOT (X_CENTER+Y, Y_CENTER-X

        TEST    [P_VAL], 8000H      ;TEST P FOR NEGATIVE VALUE
```

```
                JNS      P_DECY
                MOV      CL, 2             ;P := P + (4 * X) + 6
                MOV      AX, [X_REL]
                SHL      AX, CL
                ADD      AX, 6
                ADD      [P_VAL], AX
                ADD      [X_REL], 1        ;INCREMENT X COUNT
                JMP      CIRC_LP
P_DECY:         MOV      CL, 2             ;P := P + 4 * (X - Y) + 10
                MOV      AX, [X_REL]
                SUB      AX, [Y_REL]
                SHL      AX, CL
                ADD      AX, 10
                ADD      [P_VAL], AX
                SUB      [Y_REL], 1        ;DECREMENT Y COUNT
                ADD      [X_REL], 1        ;INCREMENT X COUNT
                JMP      CIRC_LP
END PROC CIRCLE;
;*****************************************************************
;*****************************************************************
;PROCEDURE CIR_PIXEL ACCEPTS AS INPUT A RELATIVE BYTE ADDRESS AND AN
;X COORDINATE POSITION AND SETS THE CORRESPONDING PIXEL
PROC CIR_PIXEL;
                MOV      [SEGMENT_E], ES    ;SAVE SEG E STATUS
                POP      [RET_CPE]         ;SAVE RETURN ADDRESS
                POP      DX                ;GET X POSITION
                POP      BX                ;GET RELATIVE BYTE ADDRESS
                AND      DX, 7
                JNZ      CPBIT1
                MOV      AL, 80H
                MOV      CL, 7FH
                JMP      CPIX_ON
CPBIT1:         SUB      DL, 1
                JNZ      CPBIT2
                MOV      AL, 40H
                MOV      CL, 0BFH
                JMP      CPIX_ON
CPBIT2:         SUB      DL, 1
                JNZ      CPBIT3
                MOV      AL, 20H
                MOV      CL, 0DFH
                JMP      CPIX_ON
CPBIT3:         SUB      DL, 1
                JNZ      CPBIT4
                MOV      AL, 10H
                MOV      CL, 0EFH
                JMP      CPIX_ON
CPBIT4:         SUB      DL, 1
                JNZ      CPBIT5
                MOV      AL, 8
                MOV      CL, 0F7H
                JMP      CPIX_ON
CPBIT5:         SUB      DL, 1
                JNZ      CPBIT6
                MOV      AL, 4
                MOV      CL, 0FBH
                JMP      CPIX_ON
CPBIT6:         SUB      DL, 1
                JNZ      CPBIT7
                MOV      AL, 2
                MOV      CL, 0FDH
                JMP      CPIX_ON
CPBIT7:         MOV      AL, 1
                MOV      CL, 0FEH
CPIX_ON:        MOV      DX, 0C000H       ;CLEAR ALL COLOR PLANES AT SELECTED
                MOV      ES, DX           ;PIXEL LOCATION BEFORE SETTING
                SEG      ES               ;PIXEL TO DESIRED COLOR
                AND      [BX], CL
                MOV      DX, 0D000H
```

```
            MOV         ES, DX
            SEG         ES
            AND         [BX], CL
            MOV         DX, 0E000H
            MOV         ES, DX
            SEG         ES
            AND         [BX], CL
            MOV         DX, [COL_PL1] ;SET PIXEL TO DESIRED COLOR
            MOV         ES, DX
            SEG         ES
            OR          [BX], AL
            MOV         DX, [COL_PL2]
            MOV         ES, DX
            SEG         ES
            OR          [BX], AL
            MOV         DX, [COL_PL3]
            MOV         ES, DX
            SEG         ES
            OR          [BX], AL
            PUSH        [RET_CPE]
            MOV         ES, [SEGMENT_E]   ;RESTORE SEG E
            RET
END PROC CIR_PIXEL;
;*********************************************************************
;*********************************************************************
;PROCEDURE SET_PIXEL ACCEPTS AS INPUT AN (X,Y) COORDINATE AND SETS THE
;CORRESPONDING PIXEL TO THE SYSTEM COLOR
PROC SET_PIXEL;
            MOV         BP, SP
            MOV         [SEGMENT_E], ES   ;SAVE ES STATUS
            POP         [RET_SPE]         ;SAVE RETURN ADDRESS
            MOV         AX, [BP+4]        ;GET X POSITION
            MOV         [X_POS], AX
            CALL        ADJ_SL
            CALL        REL_VID_ADDR
            POP         BX                ;GET RELATIVE BYTE ADDRESS
            MOV         DX, [X_POS]
            AND         DX, 7             ;MAKE A BIT MASK
            JNZ         PBIT1
            MOV         AL, 80H
            MOV         CL, 7FH
            JMP         PIX_ON
PBIT1:      SUB         DL, 1
            JNZ         PBIT2
            MOV         AL, 40H
            MOV         CL, 0BFH
            JMP         PIX_ON
PBIT2:      SUB         DL, 1
            JNZ         PBIT3
            MOV         AL, 20H
            MOV         CL, 0DFH
            JMP         PIX_ON
PBIT3:      SUB         DL, 1
            JNZ         PBIT4
            MOV         AL, 10H
            MOV         CL, 0EFH
            JMP         PIX_ON
PBIT4:      SUB         DL, 1
            JNZ         PBIT5
            MOV         AL, 8
            MOV         CL, 0F7H
            JMP         PIX_ON
PBIT5:      SUB         DL, 1
            JNZ         PBIT6
            MOV         AL, 4
            MOV         CL, 0FBH
            JMP         PIX_ON
PBIT6:      SUB         DL, 1
            JNZ         PBIT7
```

```
              MOV       AL, 2
              MOV       CL, 0FDH
              JMP       PIX_ON
PBIT7:        MOV       AL, 1
              MOV       CL, 0FEH
PIX_ON:       MOV       DX, 0C000H      ;CLEAR ALL COLOR PLANES AT SELECTED
              MOV       ES, DX          ;PIXEL LOCATION BEFORE SETTING
              SEG       ES              ;PIXEL TO NEW COLOR
              AND       [BX], CL
              MOV       DX, 0D000H
              MOV       ES, DX
              SEG       ES
              AND       [BX], CL
              MOV       DX, 0E000H
              MOV       ES, DX
              SEG       ES
              AND       [BX], CL
              MOV       DX, [COL_PL1]   ;SET PIXEL TO DESIRED COLOR
              MOV       ES, DX
              SEG       ES
              OR        [BX], AL
              MOV       DX, [COL_PL2]
              MOV       ES, DX
              SEG       ES
              OR        [BX], AL
              MOV       DX, [COL_PL3]
              MOV       ES, DX
              SEG       ES
              OR        [BX], AL
              PUSH      [RET_SPE]          ;RESTORE RETURN ADDRESS
              MOV       ES, [SEGMENT_E]    ;RESTORE SEGMENT E
              RET
END PROC SET_PIXEL;
;*******************************************************************
;*******************************************************************
;PROCEDURE RESET_PIXEL ACCEPTS AS INPUT AN (X,Y) COORDINATE AND RESETS
;THE CORRESPONDING PIXEL BY WRITING "0" TO ALL COLOR PLANES
PROC RESET_PIXEL;
              MOV       BP, SP
              MOV       [SEGMENT_E], ES ;SAVE ES STATUS
              POP       [RET_RPE]       ;SAVE RETURN ADDRESS
              MOV       AX, [BP+4]      ;GET X POSITION
              MOV       [X_POS], AX
              CALL      ADJ_SL
              CALL      REL_VID_ADDR
              POP       BX              ;GET RELATIVE BYTE ADDRESS
              MOV       DX, [X_POS]
              AND       DX, 7           ;MAKE A BIT MASK
              JNZ       RBIT1
              MOV       AL, 7FH
              JMP       PIX_OFF
RBIT1:        SUB       DL, 1
              JNZ       RBIT2
              MOV       AL, 0BFH
              JMP       PIX_OFF
RBIT2:        SUB       DL, 1
              JNZ       RBIT3
              MOV       AL, 0DFH
              JMP       PIX_OFF
RBIT3:        SUB       DL, 1
              JNZ       RBIT4
              MOV       AL, 0EFH
              JMP       PIX_OFF
RBIT4:        SUB       DL, 1
              JNZ       RBIT5
              MOV       AL, 0F7H
              JMP       PIX_OFF
RBIT5:        SUB       DL, 1
              JNZ       RBIT6
```

```
            MOV         AL, 0FBH
            JMP         PIX_OFF
RBIT6:      SUB         DL, 1
            JNZ         RBIT7
            MOV         AL, 0FDH
            JMP         PIX_OFF
RBIT7:      MOV         AL, 0FEH
PIX_OFF:    MOV         DX, 0C000H
            MOV         ES, DX
            SEG         ES
            AND         [BX], AL
            MOV         DX, 0D000H
            MOV         ES, DX
            SEG         ES
            AND         [BX], AL
            MOV         DX, 0E000H
            MOV         ES, DX
            SEG         ES
            AND         [BX], AL
            PUSH        [RET_RPE]          ;RESTORE RETURN ADDRESS
            MOV         ES, [SEGMENT_E]    ;RESTORE SEGMENT E
            RET
END PROC RESET_PIXEL;
;*******************************************************************
;*******************************************************************
;PROCEDURE INQUIRE_COLOR IS USED TO INTERFACE WITH HIGHER LEVEL ADA
;PROGRAMS IN ORDER TO HANDLE I/O PARAMETER PASSING
PROC INQUIRE_COLOR;
            MOV         BP, SP
            PUSH        BP
            PUSH        [BP+6]            ;PUSH X POSITION
            PUSH        [BP+4]            ;PUSH Y POSITION
            CALL        INQ_COLOR         ;GET PIXEL COLOR
            POP         AX                ;COLOR VAL RETURNED
            POP         BP
            MOV         BX, [BP+2]
            MOV         [BX], AX          ;RETURN PIXEL COLOR
            RET
END PROC INQUIRE_COLOR;
;*******************************************************************
;*******************************************************************
;PROCEDURE INQ_COLOR ACCEPTS X & Y COORDINATES AS AN INPUT AND
;RETURNS THE PIXEL COLOR CODE OF THAT LOCATION
PROC INQ_COLOR;
            MOV         BP, SP
            MOV         AX, [BP+4]
            MOV         [X_POS], AX
            POP         [RET_IC]         ;SAVE RETURN ADDRESS
            CALL        ADJ_SL
            CALL        REL_VID_ADDR
            POP         BX
            PUSH        [X_POS]
            CALL        X_MASK
            POP         CX               ;READ MASK
            PUSH        ES               ;SAVE ES STATUS
            MOV         AX, 0C000H
            MOV         ES, AX
            SEG         ES
            MOV         DL, [BX]         ;READ DATA IN BLUE BIT PLANE
            AND         DL, CL           ;TEST IF BIT SET
            JNZ         B1
            JMP         NO_B
B1:         MOV         AX, 0D000H
            MOV         ES, AX
            SEG         ES
            MOV         DL, [BX]         ;READ DATA IN RED BIT PLANE
            AND         DL, CL           ;TEST IF BIT SET
            JNZ         B2
            JMP         B_NO_R
```

```
B2:         MOV     AX, 0E000H      ;RED IS SET, TEST GREEN
            MOV     ES, AX
            SEG     ES
            MOV     DL, [BX]        ;READ DATA IN GREEN BIT PLANE
            AND     DL, CL          ;TEST IF BIT IS SET
            JNZ     B3
            JMP     BR_NO_G
B3:         MOV     AX, 0           ;COLOR IS WHITE
            JMP     EXIT_IC
BR_NO_G:    MOV     AX, 2           ;COLOR IS MAGENTA
            JMP     EXIT_IC
B_NO_R:     MOV     AX, 0E000H     ;BLUE IS SET, RED IS NOT, TEST GREEN
            MOV     ES, AX
            SEG     ES
            MOV     DL, [BX]        ;READ DATA IN GREEN BIT PLANE
            AND     DL, CL
            JNZ     B4
            JMP     B_NO_RG
B4:         MOV     AX, 1           ;COLOR IS CYAN
            JMP     EXIT_IC
B_NO_RG:    MOV     AX, 3           ;COLOR IS BLUE
            JMP     EXIT_IC
NO_B:       MOV     AX, 0D000H      ;NO BLUE, TEST RED
            MOV     ES, AX
            SEG     ES
            MOV     DL, [BX]        ;READ DATA IN RED BIT PLANE
            AND     DL, CL
            JNZ     B5              ;RED IS SET, NO BLUE, TEST GREEN
            JMP     NO_BR
B5:         MOV     AX, 0E000H
            MOV     ES, AX
            SEG     ES
            MOV     DL, [BX]        ;READ DATA IN GREEN BIT PLANE
            AND     DL, CL
            JNZ     B6
            JMP     R_NO_BG
B6:         MOV     AX, 4           ;COLOR IS YELLOW
            JMP     EXIT_IC
R_NO_BG:    MOV     AX, 6           ;COLOR IS RED
            JMP     EXIT_IC
NO_BR:      MOV     AX, 0E000H      ;NO BLUE, NO RED, TEST GREEN
            MOV     ES, AX
            SEG     ES
            MOV     DL, [BX]        ;READ DATA IN GREEN BIT PLANE
            AND     DL, CL
            JNZ     B7
            JMP     NO_RGB
B7:         MOV     AX, 5           ;COLOR IS GREEN
            JMP     EXIT_IC
NO_RGB:     MOV     AX, 7           ;COLOR IS BLACK
EXIT_IC:    POP     ES              ;RESTORE ES
            PUSH    AX
            PUSH    [RET_IC]        ;RESTORE RETURN ADDRESS
            RET
END PROC INQ_COLOR;
;*******************************************************************
;*******************************************************************
;PROCEDURE X_MASK ACCEPTS AN X COORDINATE POSITION AS INPUT
;AND RETURNS A BIT MASK BASED ON THE X COORDINATE
PROC X_MASK;
            POP     DX              ;SAVE RETURN ADDRESS
            POP     AX              ;GET X POSITION
            AND     AX, 7
            JNZ     MBIT1
            MOV     AX, 80H
            JMP     EXIT_XM
MBIT1:      SUB     AX, 1
            JNZ     MBIT2
            MOV     AX, 40H
```

```
                JMP         EXIT_XM
MBIT2:          SUB         AX, 1
                JNZ         MBIT3
                MOV         AX, 20H
                JMP         EXIT_XM
MBIT3:          SUB         AX, 1
                JNZ         MBIT4
                MOV         AX, 10H
                JMP         EXIT_XM
MBIT4:          SUB         AX, 1
                JNZ         MBIT5
                MOV         AX, 8
                JMP         EXIT_XM
MBIT5:          SUB         AX, 1
                JNZ         MBIT6
                MOV         AX, 4
                JMP         EXIT_XM
MBIT6:          SUB         AX, 1
                JNZ         MBIT7
                MOV         AX, 2
                JMP         EXIT_XM
MBIT7:          MOV         AX, 1
EXIT_XM:        PUSH        AX                  ;RETURN X MASK
                PUSH        DX                  ;RESTORE RETURN ADDRESS
                RET
END PROC X_MASK;
;*******************************************************************
;*******************************************************************
;PROCEDURE BOUNDARY_FILL ACCEPTS AS INPUT X AND Y COORDINATES, A FILL
;COLOR, AND A BOUNDARY COLOR AND PERFORMS A SCREEN FILL WITH THE
;FILL COLOR UP TO THE SPECIFIED BOUNDARY
PROC BOUNDARY_FILL;
                POP         [RET_FILL]
                POP         [B_COLOR]
                POP         [F_COLOR]
                MOV         [SEGMENT_FE], ES
                MOV         AX, [COL_PL1]
                MOV         [SAV_COL1_STAT], AX
                MOV         AX, [COL_PL2]
                MOV         [SAV_COL2_STAT], AX
                MOV         AX, [COL_PL3]
                MOV         [SAV_COL3_STAT], AX
                CALL        B_FILL
                PUSH        [RET_FILL]
                MOV         ES, [SEGMENT_FE]
                MOV         AX, [SAV_COL1_STAT]
                MOV         [COL_PL1], AX
                MOV         AX, [SAV_COL2_STAT]
                MOV         [COL_PL2], AX
                MOV         AX, [SAV_COL3_STAT]
                MOV         [COL_PL3], AX
                RET
END PROC BOUNDARY_FILL;
;*******************************************************************
;*******************************************************************
;PROCEDURE R_FILL IS THE RECURSIVE PART OF THE BOUNDARY FILL PROCEDURE.
;IT IS USED TO AVOID UNNECESSARY PASSING OF THE COLOR PARAMETERS WHICH
;DO NOT CHANGE ON SUCCESSIVE RECURRSIVE CALLS.
PROC B_FILL;
                POP         DX                  ;SAVE RETURN ADDRESS
                MOV         CX, [X_POS]
                MOV         BX, [Y_POS]
                POP         [Y_POS]             ;GET NEXT Y POSITION OFF STACK
                POP         [X_POS]             ;GET NEXT X POSITION OFF STACK
                PUSH        DX
                PUSH        CX
                PUSH        BX
                PUSH        [X_POS]             ;SAVE PRESENT X POSITION
                PUSH        [Y_POS]             ;SAVE PRESENT Y POSITION
```

```
            CALL      INQ_COLOR
            POP       AX
            MOV       [P_COLOR], AX    ;COMPARE COLOR AT PRESENT LOCATION
            CMP       AX, [B_COLOR]    ;WITH BOUNDARY COLOR
            JNZ       TEST_FC
            JMP       EXIT_F
TEST_FC:    MOV       AX, [P_COLOR]    ;COMPARE COLOR AT PRESENT LOCATION
            CMP       AX, [F_COLOR]    ;WITH FILL COLOR
            JNZ       F_PIX
            JMP       EXIT_F
F_PIX:      PUSH      [X_POS]
            PUSH      [Y_POS]
            CALL      ADJ_SL
            CALL      REL_VID_ADDR
            PUSH      [X_POS]
            PUSH      [F_COLOR]
            CALL      COLOR
            CALL      CIR_PIXEL        ;SET LOCATION (X,Y) TO FILL COLOR
            MOV       AX, [X_POS]
            ADD       AX, 1
            PUSH      AX
            PUSH      [Y_POS]
            CALL      B_FILL           ;CALL B_FILL PASSING (X+1,Y)
            MOV       AX, [X_POS]
            SUB       AX, 1
            PUSH      AX
            PUSH      [Y_POS]
            CALL      B_FILL           ;CALL B_FILL PASSING (X-1,Y)
            MOV       AX, [Y_POS]
            ADD       AX, 1
            PUSH      [X_POS]
            PUSH      AX
            CALL      B_FILL           ;CALL B_FILL PASSING (X,Y+1)
            MOV       AX, [Y_POS]
            SUB       AX, 1
            PUSH      [X_POS]
            PUSH      AX
            CALL      B_FILL           ;CALL B_FILL PASSING (X,Y-1)
EXIT_F:     POP       [Y_POS]          ;RESTORE POSITION (X,Y)
            POP       [X_POS]
            RET
END PROC B_FILL;
;*************************************************************************
;*************************************************************************
;PROCEDURE AREA_FILL ACCEPTS AS INPUT AN (X,Y) POSITION AND A
;FILL COLOR.  IT FILLS AN AREA WHOSE BOUNDARY IS DETERMINED BY THE
;PRESENT COLOR OF THE INPUT (X,Y) POSITION.
PROC AREA_FILL;
            POP       [RET_AFILL]      ;SAVE RETURN ADDRESS
            MOV       [SEGMENT_FE], ES
            MOV       AX, [COL_PL1]
            MOV       [SAV_COL1_STAT], AX
            MOV       AX, [COL_PL2]
            MOV       [SAV_COL2_STAT], AX
            MOV       AX, [COL_PL3]
            MOV       [SAV_COL3_STAT], AX
            POP       [F_COLOR]        ;GET FILL COLOR OFF OF STACK
            POP       [Y_POS]
            POP       [X_POS]
            PUSH      [X_POS]
            PUSH      [Y_POS]
            CALL      INQ_COLOR        ;GET COLOR OF INPUT POSITION
            POP       [B_COLOR]        ;SAVE REFERENCE COLOR
            PUSH      [X_POS]
            PUSH      [Y_POS]
            CALL      A_FILL           ;CALL RECURSIVE FILL PROCEDURE
            PUSH      [RET_AFILL]      ;RESTORE RETURN ADDRESS
            MOV       ES, [SEGMENT_FE]
            MOV       AX, [SAV_COL1_STAT]
```

```
                MOV         [COL_PL1], AX
                MOV         AX, [SAV_COL2_STAT]
                MOV         [COL_PL2], AX
                MOV         AX, [SAV_COL3_STAT]
                MOV         [COL_PL3], AX
                RET
END PROC AREA_FILL;
;*******************************************************************
;*******************************************************************
;PROCEDURE A_FILL IS THE RECURSIVE PART OF THE AREA FILL PROCEDURE.
;IT IS USED TO AVOID UNNECESSARY PASSING OF THE COLOR PARAMETERS WHICH
;DO NOT CHANGE ON SUCCESSIVE RECURRSIVE CALLS.
PROC A_FILL;
                POP         DX                  ;SAVE RETURN ADDRESS
                MOV         CX, [X_POS]
                MOV         BX, [Y_POS]
                POP         [Y_POS]             ;GET NEXT Y POSITION OFF STACK
                POP         [X_POS]             ;GET NEXT X POSITION OFF STACK
                PUSH        DX
                PUSH        CX
                PUSH        BX
                PUSH        [X_POS]             ;SAVE PRESENT X POSITION
                PUSH        [Y_POS]             ;SAVE PRESENT Y POSITION
                CALL        INQ_COLOR
                POP         AX
                MOV         [P_COLOR], AX       ;COMPARE COLOR AT PRESENT LOCATION
                CMP         AX, [B_COLOR]       ;WITH AREA COLOR
                JNZ         EXIT_AF
                PUSH        [X_POS]
                PUSH        [Y_POS]
                CALL        ADJ_SL
                CALL        REL_VID_ADDR
                PUSH        [X_POS]
                PUSH        [F_COLOR]
                CALL        COLOR
                CALL        CIR_PIXEL           ;SET LOCATION (X,Y) TO FILL COLOR
                MOV         AX, [X_POS]
                ADD         AX, 1
                PUSH        AX
                PUSH        [Y_POS]
                CALL        A_FILL              ;CALL A_FILL PASSING (X+1,Y)
                MOV         AX, [X_POS]
                SUB         AX, 1
                PUSH        AX
                PUSH        [Y_POS]
                CALL        A_FILL              ;CALL A_FILL PASSING (X-1,Y)
                MOV         AX, [Y_POS]
                ADD         AX, 1
                PUSH        [X_POS]
                PUSH        AX
                CALL        A_FILL              ;CALL A_FILL PASSING (X,Y+1)
                MOV         AX, [Y_POS]
                SUB         AX, 1
                PUSH        [X_POS]
                PUSH        AX
                CALL        A_FILL              ;CALL A_FILL PASSING (X,Y-1)
EXIT_AF:        POP         [Y_POS]
                POP         [X_POS]
                RET
END PROC A_FILL;
;*******************************************************************
;*******************************************************************
MAIN:
END ADAGRAPH;
```

LIST OF REFERENCES

1. *Technical Manual, Hardware, Z-100 Series Computers*, Zenith Data Systems Corporation, 1983.

2. Draft Department of Defense Directive 5000.31, *Computer Language Programming Policy*, Computer Software & Systems (OUSDR&AT), The Pentagon, Washington, DC, 1983.

3. Wagner, Patrice M., "Ada and Graphics, Implications of the DOD Directive," *Computer Graphics World*, February 1985.

4. *American National Standard, X3.124.3-198X, Graphical Kernel System*, by Technical Committee X3H3 - Computer Graphics, American National Standards Committee X3 - Information Processing Systems, Computer and Business Equipment Manufacturers Association, June 1986.

5. *JANUS Ada Package, User Manuals*, Software, Inc., 1983.

6. *CP M-86 Operating System User's Guide*, Digital Research, 1982.

7. Berger, Marc, *Computer Graphics with Pascal*, The Benjamin Cummings Publishing Company, Inc., 1986.

8. Hearn, Donald and Baker, M. Pauline, *Computer Graphics*, Prentice-Hall, 1986.

BIBLIOGRAPHY

Barnes, J. G. P., *Programming in Ada*, Addison-Wesley Publishing Company, 1984.

Booch, Grady, *Software Engineering with Ada*, The Benjamin Cummings Publishing Company, Inc., 1983.

Bray, Gary and Pokrass, David, *Understanding Ada*, John Wiley & Sons, 1985.

Coomes, Kenneth W., *Tactical Display Simulation on the H Z-100*, Master's Thesis, Naval Postgraduate School, Monterey, California, March 1986.

Foley, J. D. and Van Dam, A., *Fundamentals of Interactive Computer Graphics*, Addison-Wesley Publishing Company, 1982.

Rector, Russell and Alexy, George, *The 8086 Book*, Osborne McGraw-Hill, 1980.

United States Department of Defense, *Reference Manual for the Ada Programming Language*, ANSI MIL-STD-1815A-1983, Springer-Verlag, 1983.

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